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CONTENTS

Spectroscopy in Industry ..... GEORGE R. HARRISON 1

The Flight of the Projectile ..... R. H. KENT 19

On the Rôle of Tube Walls, and Surface and Space Charges in Electrical Discharges through Rarefied Gases ..... JOHN ZELENY 35

The Science Museum in London ..... H. PHILIP SPRATT 67

Critical Remarks on the Interpretation of Quantum Theory ..... ALFRED LANDÉ 83

Notes from the National Bureau of Standards 99

The Franklin Institute Notes 105

Book Reviews 107

Publications Received 117

Current Topics 18, 34, 66, 119

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SPECTROSCOPY IN INDUSTRY.*

BY

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The spectroscope, long recognized as one of the most powerful tools of scientific investigation, has been used during the past forty years to obtain information which has revolutionized physics, chemistry, and astronomy, and greatly affected biology, metallurgy, and medicine. Since many modern industries rest on scientific discoveries in these fields, it would be surprising if the spectroscope were not found useful in connection with technological processes. So rapidly, in fact, are spectroscopic methods now being adopted by industrial laboratories, that most manufacturers of spectroscopic equipment are having difficulty in keeping up with orders for their instruments, and some are even beginning to worry about the availability of such raw materials as crystal quartz, needed for prisms and other optical parts. Spectroscopic methods have been found particularly valuable in the metals industries, in those industries which involve the canning and packaging of foods, and in all other industries which use materials whose purity must be carefully determined and controlled.

The spectroscope has served the physicist and the astronomer as a telescope, a microscope, a speedometer, a thermom-

* Presented at a meeting held Thursday, February 3, 1938.

(Note—The Franklin Institute is not responsible for the statements and opinions advanced by contributors to the JOURNAL.)

eter, a tape measure, and a clock, in addition to its more usual functions, and in each role it has exceeded in range and power the more common forms of these devices. Today in industry its greatest usefulness is found in applications which supplement chemical wet methods of qualitative and quantitative analysis, and with its aid our ability to detect and measure small quantities of material has been extended very greatly.

As has often been pointed out, a teaspoonful of salt cannot hide from a spectroscope in a swimming-pool full of water. Though far less gold than would repay concentration is found in sea water, the spectroscope has no difficulty in detecting the small amount which is there. Such sensitivity might appear excessive for industrial purposes, where ability to detect a trace of almost any element in any given sample would seem valueless if nothing could be done about its presence. Fortunately, something usually can be done. Though in many cases the properties of metals are greatly influenced by traces of impurities too minute to be eliminated conveniently by ordinary methods of purification, addition of minute quantities of other impurities will often offset undesired characteristics. In the case of fusible alloys for safety valves or fire sprinklers, for example, certain impurities if present by as much as one part in ten thousand will raise the melting point by undesirable amounts. A relatively small number of atoms in the crystal boundaries can produce a marked effect, but atoms of other materials which will depress the melting point again to its proper value can be added. The spectroscope is invaluable in determining which impurities are responsible for such effects, and which elements must be added to offset them.

The outstanding value of the spectrograph comes in qualitative analysis. Let us watch two scientists looking at a tiny piece of lamp filament. To all outward appearances it is exactly the same as any other piece of filament, but in an incandescent lamp it was found to last twice as long as did filaments made from ordinary wire. There is not enough material to analyze chemically, for the sample is small and no advance hint tells what to look for. A chemist using ordinary methods would be forced to guess as to which

elements were most probably present, and eliminate them one after another. Long before he was finished such a small sample would probably be exhausted. But here is a spectrograph; the operator loads it with a photographic plate, opens the shutter, and inserts a tiny piece of the filament into an electric arc placed in front of the instrument. There is a flash of colored light and the spectrum is recorded. Shifting the plate the operator repeats the process, the second time burning a piece of an ordinary filament. When he develops the spectrogram the story stands completely revealed. Each type of atom in each filament has sent out its own group of waves of different lengths, and produced its own pattern of spectrum lines. By looking for differences in these patterns, and identifying the elements from which the various lines which differ are known to originate, the spectroscopist can see quickly and accurately which elements are present in one filament and not in the other.

The pattern of lines on a spectrum photograph may look complicated and meaningless to the layman, but to the experienced spectroscopist it often tells a story as definite as that told by a line of printing. This was perhaps not realized by the advertising agents of a manufacturer of motor cars who recently strove to impress the American public with the scientific methods used in his factory, by printing in some of the leading weeklies full page advertisements which pictured a laboratory worker gazing at a spectrogram, with the caption "Eyes That See Through Steel." The description which followed of the value of the spectroscope in perfecting automobile parts was a very good one, but every line in the spectrum at which the man was looking quite obviously had come from zinc atoms!

Spectroscopic analysis indicates that no entirely pure sample of any metal has ever been prepared, and since single foreign atoms placed here and there in the lattice structure of a metallic crystal can greatly affect its properties, really pure metals probably have properties with which as yet we are not familiar.

In the food preserving industries the spectrograph is coming into very wide application. That two or three parts of aluminum or lead can be detected readily in ten million

parts of lobster or condensed milk may seem unimportant, since such concentrations are below the toxic limits considered dangerous to health, yet obviously tests on the rapidity with which the internal coatings of cans dissolve in foods stored within them can be made more easily and quickly when such sensitive methods of detection are available. Chocolate and chewing gum manufacturers use spectroscopic analysis to insure that the lead content of their products is below the limits set by pure food laws. Whiskey distillers, finding something in their product which causes it to turn cloudy, have used the spectrograph to locate the cause in minute amounts of cadmium, let us say, (to cloak the real offender in anonymity); and by analyzing samples from various parts of the distillery line, have been enabled to locate the coil or condenser which introduced the offending element.

Has the arsenic and lead been properly removed from sprayed fruits before canning? The spectrograph will tell. Is beer kept in cans dissolving anything more from the container than it would if kept in bottles? Again, the spectrograph gives an easy means of deciding.

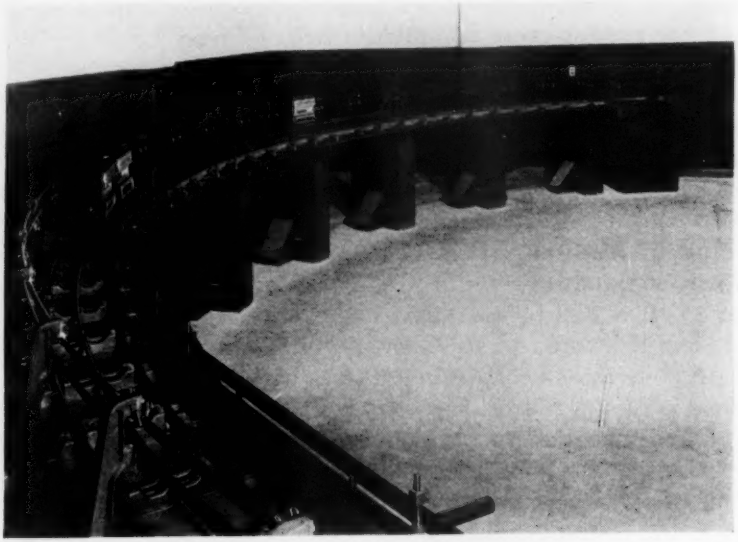
Spectroscopic analyses can be performed by two entirely independent and dissimilar means, which have different applications. In emission analysis, use is made of the characteristic light emitted when the material is burned electrically in front of the slit of a spectrograph. In the second method, absorption spectrophotometry, light waves of every length in the desired region are sent through the material to be analyzed (which must be somewhat transparent, like glass or blood serum or peppermint extract or beer) and the spectrograph is used to determine how much of the light of each wave-length has been absorbed by the material.

By the first method, seventy of the chemical elements can readily be detected and measured. The permanent gases, carbon, and a few other non-metallic elements produce few lines in the spectral regions commonly photographed, and since almost all molecules are dissociated in the arc into their constituent atoms, organic materials are burned away without appearing in the analysis. When an apple or a cranberry is ashed in an electric arc, for example, the strongest lines which

appear in the spectrum are those due to such elements as sodium and copper and iron.

When one is interested in molecules the second method of spectrographic analysis can be used. Though its application is limited to materials which are somewhat transparent, it has the advantage of not affecting the material which is being analyzed, since this is merely penetrated by a beam of light.

FIG. 1.



Section of a large concave grating spectrograph at the Massachusetts Institute of Technology, which covers over 1200 square feet of floor space. The spectrum lines are photographed with high precision on forty feet of photographic plates clamped to the tracks shown.

The modern spectroscope is not the small brass tube standing on a tripod so familiar to chemistry students, who have used it to observe the colored lines produced by different salts when burned in a flame. One of the research instruments used for precise work may fill a room forty feet square (as shown in Fig. 1), and several laboratories contain more than a dozen different types of spectrographs. For industrial work three main types are in most common use. The quartz prism instrument of medium size, which records on one plate the spectrum between the limits 5000 Angstroms and 2000

Angstroms, is useful for absorption spectrophotometry, since the absorption bands of solids or liquids are usually so wide that great separation of the waves of different lengths is valueless. This instrument can also be used for emission analysis where the substances being studied have fairly simple spectra, such as the alkalies and alkaline earths, and in general those atoms which lie on the left-hand side of the Periodic Table. Iron and most other atoms of the long periods have such complex spectra that greater resolution of the lines is required, and a large quartz instrument of the Littrow type is most commonly used. This records in three settings the part of the spectrum most important for analytical purposes, lying between 2000 Angstroms and 5000 Angstroms, when a quartz prism is used, and a glass prism can be substituted with which the visible spectrum can also be recorded.

The concave diffraction grating spectrograph has long been considered one of the more convenient types of spectrograph in research laboratories, and this instrument is now slowly making its way into industrial use. It has the advantage that it can be used with light waves of any length from the long infra-red to the shortest ultraviolet, a single instrument covering all the desired ranges without change of optical parts. Again, the grating produces almost uniform dispersion from the shortest to the longest wave-lengths, whereas the dispersion of a prism decreases rapidly toward longer wave-lengths, which makes identification of the lines easier and uses the photographic plate more effectively. The new aluminum gratings on glass, ruled by R. W. Wood at Johns Hopkins, have done much to remove prejudice against the grating because of the comparatively low intensity of the spectra it produces. Several of Wood's gratings produce spectra more intense than those produced by prisms, and with such a grating exposures in which thousands of lines from an iron arc are recorded in five seconds are not uncommon.

Some industrial users of spectrographs who express great satisfaction with their prism instruments consider the grating spectrograph too fragile for use in their laboratories. This speaks well for the prism type of instrument, but usually bespeaks lack of familiarity with the grating. Where good

prism and grating instruments are both available the grating instrument is commonly the favorite, and that it cannot be the delicate apparatus sometimes supposed is borne out by its very satisfactory use in such metallurgical laboratories as those of the Watertown Arsenal and the Cleveland Lamp Works.

As a typical example of all-around use of the spectrograph in attacking an industrial problem, I shall discuss the spectroscopic procedure connected with what we may call "The Case of the Hafnium Crystals." (The real crystals were not hafnium, nor were they, in fact, crystals.) The spectroscopic procedure used was so varied that the case serves as an excellent illustration. The problem was to locate minute deposits of hafnium in a certain transparent crystalline material, and to measure the distribution and amount of the hafnium in typical crystals. The spectrographic method was selected as one of the best ways of doing this.

First, emission analysis was used to determine the amount of hafnium present in the crystal material. Several milligrams of the material were burned in an electric arc, and the light emitted was photographed with a spectrograph. The wave-lengths of all lines appearing on the plate were then determined with an accurate measuring engine, and from published catalogs of wave-lengths all lines appearing on the plate were assigned to their parent atoms. A qualitative analysis of all metallic elements present in amounts greater than about one part in a million was thus obtained.

A spectrographic quantitative analysis was next made. From the qualitative analysis the elements could be grouped into three classes by observing the intensities of their spectrum lines. Those which were present in large concentrations (above about 1 per cent.) were listed as major constituents, those present in amounts lying between 1 and 0.001 per cent. were listed as minor constituents, and those present in smaller amounts as traces.

In general, one may say that for major constituents, spectroscopic methods of quantitative analysis are slightly inferior in precision to chemical wet methods, for minor constituents they are equal in precision, and for traces they are superior, assuming sufficiently large samples are available

to make adequate chemical analyses. Spectroscopic methods have their greatest advantage when the samples available are small, or concentrations are low, because the precision of the spectroscopic method stays sensibly constant at all concentrations. With it one can distinguish as readily between 0.0010 and 0.0011 per cent. concentration of material as between 10 and 11 per cent., for example.

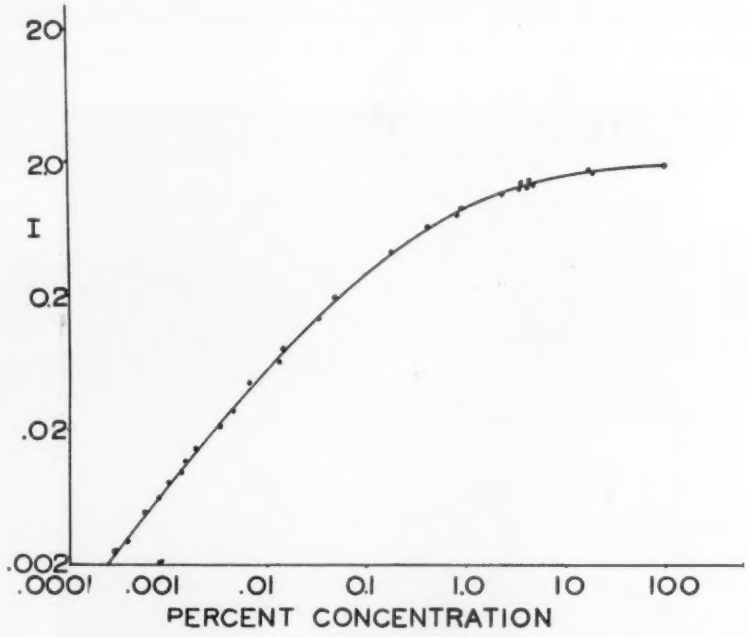
The concentration of a minor constituent is determined by observation of the intensities of its spectrum lines relative to those of the matrix material (which is composed of the major constituents), and as these ratios vary with a number of factors, a null method must be used. Standard comparison samples are made up which differ from the sample to be measured only in regard to the constituent being measured, and these samples and this unknown are burned and photographed in identical manner. Then, if the intensities of the lines of the constituent in question are the same in any comparison sample as in the unknown sample, the concentration of the constituent will be the same in the two samples.

Such rigid conditions might seem impossible to fulfill, but fortunately any number of minor constituents and traces may differ in the known and unknown samples without affecting the result. If we are comparing the copper content of two bronzes, for example, error may result if lead be present in one sample in amounts greater than 1 per cent., and not in the other, but in amounts less than about 1 per cent. a difference in lead content should not affect the results appreciably.

Returning to the crystal problem, having made up a series of samples of the material containing various known concentrations of hafnium covering the range suggested by the qualitative analysis, we now burn these in the arc in succession, sandwiched between alternate exposures burning the unknown sample. When the plate has been developed, fixed, and dried, we can measure the amount of blackening of each of the hafnium lines on a microdensitometer, and plot a "working curve" of density against concentration. Or, as is more common, by calibrating the plates we can change densities into the actual line intensities to which they correspond, and plot intensity against $\log_{10}$ concentration. At

low concentrations such a plot is usually a straight line (as shown in Fig. 2) which aids greatly in interpolating between two standard intensities. By this means, using care, precision to 3 per cent. can usually be obtained, which at concentrations below 0.1 per cent. is ordinarily greater than that of chemical methods.

FIG. 2.

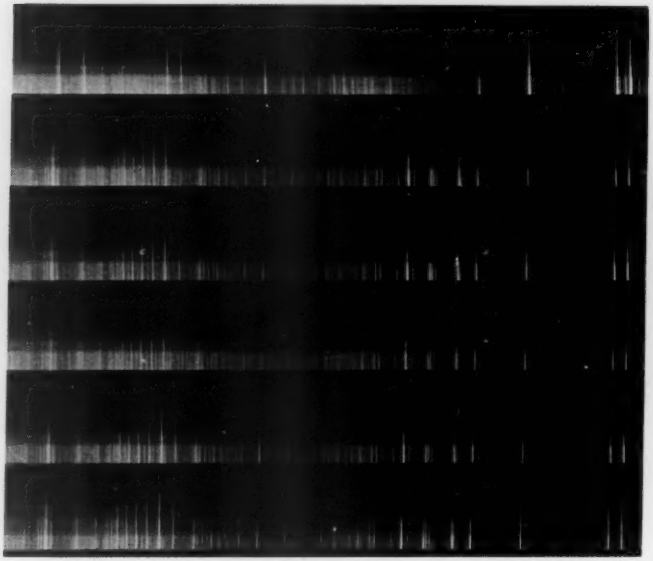


A typical working-curve, for determining the concentration of an element present in a sample burned in the electric arc, in terms of the intensity of one of its spectrum lines photographed under standard conditions. The logarithm of the percent concentration of the element is plotted against the logarithm of the intensity of the line, as determined from a number of samples of known concentration. At low concentrations the curve is theoretically a straight line having 45° slope, which greatly simplifies quantitative spectrographic analysis at low concentrations.

Having determined the actual amount of hafnium present, we are now ready to determine its location in the crystals. The first method tried was to pick out small particles of the crystal and burn them in the arc, observing visually the intensities of the visible hafnium lines with a spectroscope. A sample the size of a pinhead was found to give fairly consistent results, but particles less than 1 mm. in diameter were too likely to be lost from the arc. A series of runs was made

to determine the minimum amount of hafnium which could be detected spectroscopically. A weighed sample of the material, known to contain 10^{-5} grams of hafnium, was introduced into a 2 amp. arc between pure graphite electrodes. Strong hafnium lines were found to be still visible in the spectroscope after 1000 seconds of burning. The spectrum was then photographed with a high speed spectrograph, and an exposure of 0.0001 seconds was found sufficient to record

FIG. 3.



Typical portions of spectrograms taken in one type of quantitative spectrographic analysis. In this method each line is photographed in such a way that it decreases in intensity along its length, to aid in the intensity determinations.

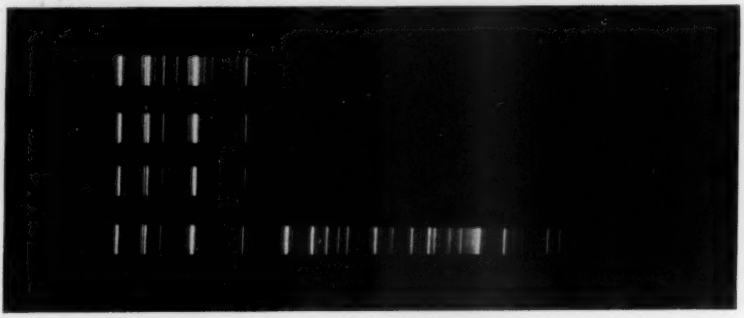
the lines. This indicates that no more than 10^{-12} grams of hafnium were required for spectrographic detection, but actually the efficiency of excitation of the hafnium atoms is much greater under these conditions than under conditions in which only the minimum detectable amount of material is introduced into the arc. 10^{-8} grams can usually be detected without difficulty, however.

Emission methods were thus shown to be insufficiently sensitive for the problem at hand. Since the crystals were

transparent, the absorption method could be tried, and this method was found satisfactory. Ultimately amounts down to 10^{-18} grams of hafnium were successfully located in the crystals by absorption methods.

The first step in this new attack was to determine the absorption spectrum of hafnium salts of the type present in the crystal. The hafnium-containing crystalline material was dissolved in water, and a quartz vessel filled with the resulting solution was placed between the light source (a hydrogen discharge tube, which gives a good continuous spectrum in the ultraviolet) and the slit of the spectrograph. On the same plate an absorption spectrogram was taken of

FIG. 4.

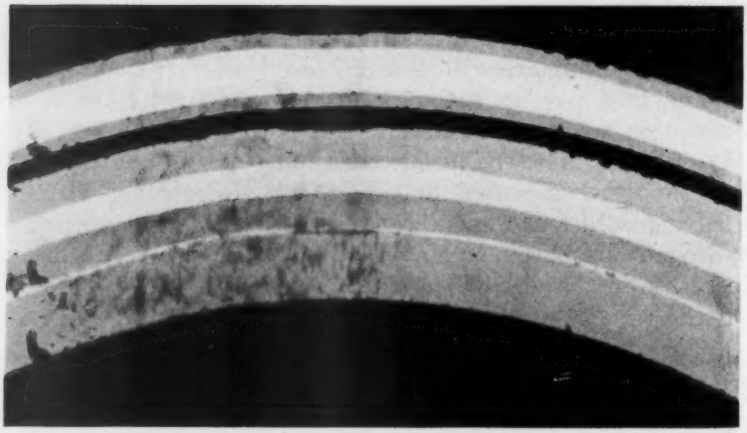


Typical absorption spectrogram. The long lower spectrum is of the unabsorbed light; the three upper spectra were taken with some of the "hafnium crystals" in the light beam, and show transparency in the green, beginning absorption in the blue and violet regions, and opacity in the ultraviolet.

similar crystal material which contained no hafnium, as shown in Fig. 4. The differences in absorption were obviously due to the hafnium salt, which was found to absorb strongly in the ultraviolet, a little in the violet, and practically not at all in the visible region.

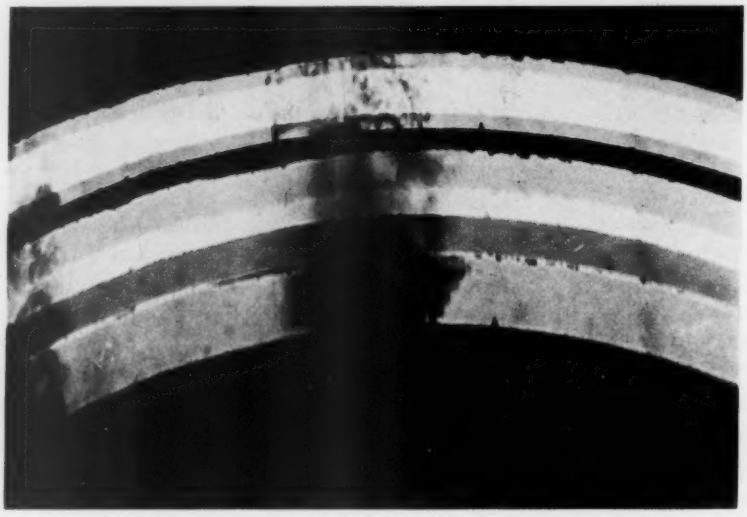
The final step was to locate spots in the crystals which showed this characteristic absorption. For this purpose a spectrograph and an ultraviolet-transmitting microscope were combined. Sections of the crystal were thus photographed in each individual line of the mercury spectrum from a quartz mercury arc. Thus the crystal was photographed under high magnification in transmitted monochromatic

FIG. 5.



"Rainbow spectrum" of crystals containing no hafnium salts, taken with a microscope and spectrograph in combination. Each "bow" is a spectrum line of a given color, and the same microscopic region is photographed in each color. The lower bow is an ultraviolet line, the upper bows are visible lines.

FIG. 6.

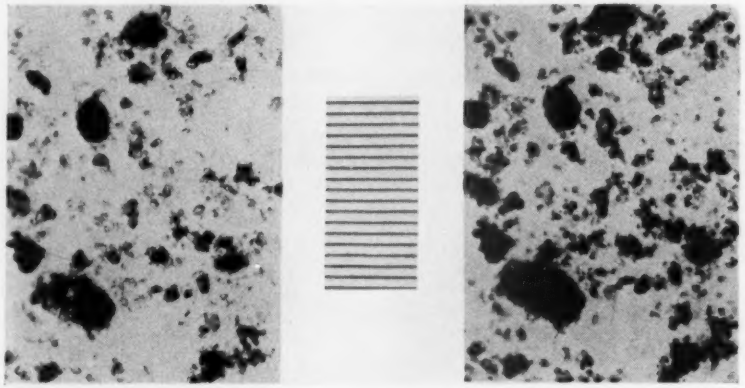


Same type of spectromicrogram as in Fig. 5, but with hafnium-containing crystals in the field. Note the darkening produced by absorption of ultraviolet light by the hafnium crystals in the lower bows and the relative transparency of the hafnium in the upper bows.

green light, in blue light, in violet light, and in the light of several ultraviolet lines.

Opaque materials in the crystal showed dark in all these photographs. Transparent materials which were not hafnium showed light in all, as in Fig. 5, where each bow contains a separate photograph. The hafnium salts showed transparent in green and blue light, darker in the violet light, and opaque in the ultraviolet, as in Fig. 6. Thus any particle which showed this progressive absorption could definitely be called a hafnium carrier, and from its opacity its hafnium concentration could be determined.

FIG. 7.



A B

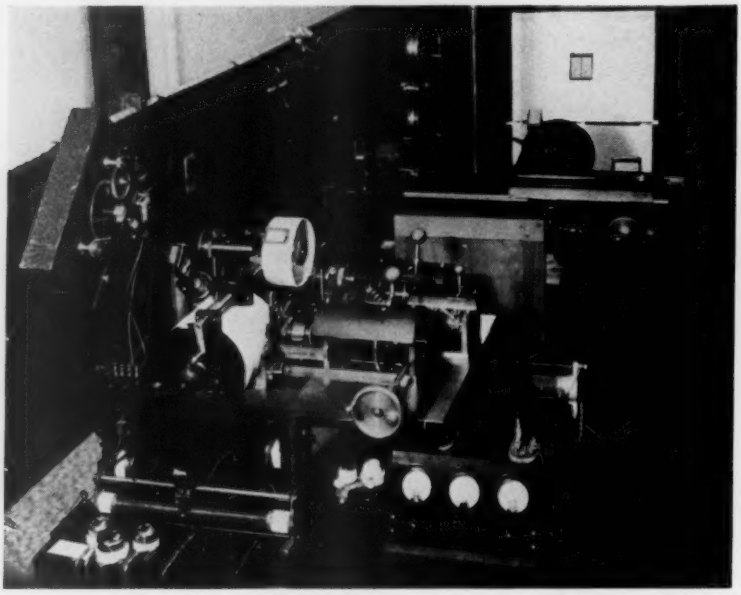
Photomicrograms taken of hafnium-crystals immersed in turpentine, A being taken with green light, and B with ultraviolet light. Any particle appearing transparent in A and opaque in B contains hafnium.

This method was then further simplified by using a microscope adapted to either visible or ultraviolet light, and taking duplicate photographs of each crystalline particle, immersed in an oil of the proper index of refraction, first with green light as in Fig 7A, and then with ultraviolet light of the desired wave-length, as in Fig. 7B. Magnifications up to 2000 diameters could be used, and thus extremely small amounts of hafnium could be located, since a layer of "hafnium" atoms only five atoms thick will give an observable degree of opacity.

Most industrial spectroscopic problems are simpler and more readily solved than the one sketched above, but it is described as illustrating a number of different methods of using a spectrograph.

For many industrial purposes it is important that speed be combined with precision. Two hundred tons of molten copper in a furnace represents a large investment which can

FIG. 8.



Automatic machine for measuring, computing, and recording the wave-lengths of spectrum lines, which has speeded up these operations some two hundred times. Over eight million measurements have recently been made at the Massachusetts Institute of Technology with this machine and an improved model, and it is expected that a new catalog of wave-lengths of spectrum lines containing the results will soon be issued. Such a set of tables is badly needed, as the last systematic set of measurements of this sort was made in 1911, and greatly improved methods are now available.

be lost through improper treatment. The copper must be removed from the furnace at the proper degree of purification, and several hours may be consumed in determining by chemical methods the proper time for removal. Often recourse is had to rule of thumb methods, for lack of anything better. An ideal solution would be a spectroscopic arrangement such that the furnace operator could periodically dip

some molten copper from the furnace, burn it before a spectroscope and decide from the appearance of certain impurity lines exactly when the proper time for removal was reached. There is no fundamental reason why this operation should take more than two minutes if performed visually or with a photoelectric cell.

Eye methods can be used in certain cases only, since many of the important lines for analysis lie in the ultraviolet region. It is, to be sure, possible to use fluorescence to observe ultraviolet lines, but this method has not yet been well developed. It awaits an increased demand from industry, which in turn awaits knowledge of the feasibility of such methods.

The photoelectric method of spectroscopic analysis has been tried with encouraging results in Germany and at the Watertown Arsenal in this country, and shows considerable promise, though it must be considered as in only a preliminary state of development. The limitation on this technic, which is simple and should be capable of precision, is in getting enough light to operate photocells from a single line of an element which is present in the sample in only small amounts, when this line is in the midst of a bewildering array of strong lines from other elements. Spectroscopes of high speed, combined with improved phototubes and amplifiers, and improved sources will probably bring ultimate perfection of this rapid method.

The photographic method can be speeded up greatly, and in at least one foundry, that of the Campbell, Wyant and Cannon Co. of Muskegon, Michigan, most of the routine chemical tests on the output of the foundry have been superseded by rapid spectrographic methods. Quick results are of great importance, and by hastening the processing of the photographic plates used a method has been developed which gives precise quantitative analyses on six elements in a single sample in fifteen minutes or less. As reported by Vincent and Sawyer [1] spectra for forty-eight analyses on eight samples are recorded on each plate, and the posting of results from a plate can be completed within thirty-five minutes after receipt

[1] H. B. Vincent and R. A. Sawyer, *Journal of Applied Physics*, March, 1937, p. 163.

of the samples. Repeat runs were found to be more consistent from the spectrographic laboratory than from the chemical laboratory for such elements as silicon, molybdenum, chromium, nickel, manganese, and copper.

Such successful utilization of the spectrograph twenty hours a day in a foundry under industrial conditions of stress, with resulting improvement in precision of results, speed, and decrease in cost, emphasizes that the spectrograph is a practical tool.

For rapid testing of raw materials special simple types of spectroscopes have been developed by various manufacturers. A notable example is the Spekker Steeloscope of Adam Hilger, Ltd. This is a small portable fixed prism spectroscope with a movable eyepiece on which are engraved the various important lines of elements which are to be sought after. A technician of moderate skill, who needs only a reasonable amount of special training, can travel from one car to another of a freight train loaded, for example, with pig iron, carrying his spectroscope and dragging behind him a 220 volt cable carrying D.C. to run an electric arc. Selecting a sample pig he strikes an arc between this and a rod of pure iron which he carries for the purpose, and observes the light through his spectroscope, with the eyepiece set for "nickel" or whatever element he is interested in. A special eyepiece can be obtained which, by a clever optical arrangement, enables the eye to compare the intensities of two lines. By setting this at some predetermined value the operator is enabled to tell at once whether the nickel content, for example, is within the limits of acceptance, and it is thus but a job of a few hours to sample and analyze a whole trainload of iron without even bothering to unload it

Such possibilities in industry are almost endless, but since special methods are required for special purposes, their application awaits the demands of industrialists. The first reaction to the spectroscope is usually amazement at its possibilities. Somewhat further investigation then frequently brings a reaction of disappointment, because it will not solve every problem which may be presented. The next reaction is that perhaps matters are not so hopeless after all, since a

little special attention to each case may show how to get around the difficulty.

So we see paper manufacturers who want to discover the scource of tiny black specks in their product, bakery equipment manufacturers who wonder if their new coating compound for pans is contaminating the dough, spark plug manufacturers who wish to study the effect of minute amounts of alkali metals in improving sparking, metallurgists who wish to trace the origins of ores, all trying spectroscopic methods, and usually finding them helpful. It should be remembered that application of such methods to industry is only beginning, and their full power can only be realized by detailed attention to such problems as are presented for solution.

Protection of Submarine Cables by Placement "Underground." —(*Electrical Engineering*, Vol. 57, No. 5.) Damage estimated at $500,000 a year is caused to transoceanic telegraph cables of the world by the heavy drags or otterboards which are attached to fishing nets dragged along the ocean bottom by steam trawlers. To protect cables in waters where they are exposed to this hazard and thereby reduce this loss, a plow has been devised by engineers of the Western Union Telegraph Co. which when pulled along the ocean bottom is expected to cut a furrow, drop the cable into it, and back fill over the cable. The first cables scheduled to be plowed under are in the fishing banks off the coast of Ireland, where damage is particularly severe. One of the major necessities for this work was a tow line capable of withstanding a 65,000 pound stress, and flexible enough to permit its management by equipment on a ship. Early experiments showed that wire rope developed torque when under strain and was too stiff for easy handling, and that only a chain was practicable for this purpose. Therefore a continuous length of 4200 feet of nickel-steel chain was obtained. Reputedly the longest chain ever manufactured in one piece, it comprises 12,500 links and weighs 43,000 pounds. It was recently loaded on the *Lord Kelvin*, flagship of the Western Union Cable repair fleet. This ship contains the necessary equipment for locating, picking up, repairing and laying of cables. When a break in a cable occurs, the position of the rupture may be determined by measurements of electrical resistance of the conductors. Records show that more than 50 per cent. of the positions may be determined within 0.5 nautical mile. Upon reaching the location the repair ship hooks the cable by passing over it at right angles. Cable that has been plowed into the ocean bottom will require a different technique for locating and grappling. This problem is being carefully studied.

R. H. O.

THE FLIGHT OF THE PROJECTILE.[1]

BY

R. H. KENT.[2]

Although you are all familiar in a general way with guns and projectiles, I hope you will be interested in a description of the flight of the projectile from its seat in the chamber of the gun through the bore to the muzzle and thence through the air to the target. This flight is the subject matter of ballistics. The motion of the projectile *in the gun* is the subject matter of *interior ballistics* while the *motion through the air* is the subject matter of *exterior ballistics*.

DESCRIPTION OF FLIGHT IN THE BORE.

The gun is a steel tube, the bore of which is rifled to impart spin to the projectile. The breech end of it has an opening through which the projectile and the powder charge are introduced, after which the breech is closed to withstand the high pressures developed. The projectile is usually a steel shell, symmetrical about its major axis, containing an explosive charge of TNT, ammonium picrate or other substance and also a fuze which sets off the explosive charge either in the air or upon impact with the target. Some powders are composed of nitrocellulose, other powders, of nitrocellulose mixed with nitroglycerin together with certain stabilizing and plasticizing substances.

Some European nations, at least for the larger guns, use powder made up in long sticks, cords or tubes, while the United States for the most part uses powder made up into small grains containing one or more perforations.

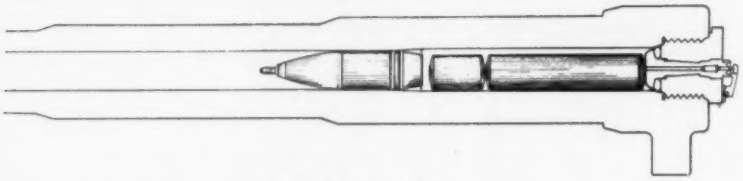
The gun shown in Fig. 1 may be considered as an engine of which the projectile is the piston and the powder charge is the fuel. In the automobile engine, a spark starts the chemical reaction required to produce the pressure to drive

[1] Presented at a meeting held Thursday, January 13, 1938 and published by permission of the Chief of Ordnance U. S. A.

[2] Ordnance Engineer, Aberdeen Proving Ground, Md.

the piston; in the gun an igniter is needed to start the chemical reaction producing a rapid generation of gas and the high pressure required for the rapid acceleration of the projectile. For the purpose of ignition black powder is usually used. The black powder itself is sometimes touched off by a high explosive like mercury fulminate detonated by percussion.

FIG. 1.



Gun, charge, projectile.

According to recent investigations, it appears that the black powder sets off the smokeless powder charge in the gun mainly by the radiation from the hot glowing particles of the black powder. While the start of the burning of the smokeless powder is due to an effect of radiation, the burning is accelerated as the pressure begins to rise by the conduction of heat from the hot powder gas to the unburned particles of the powder charge. At the present time it appears that the rate of burning of the powder, that is to say, the rate of regression of the moving surface of the powder grain is best represented by an expression of the form proposed by Petavel,

$$\text{rate of regression} = a + bp.$$

In this, a may be regarded as a constant which is a function of temperature, p is the pressure and b is another constant which is a function of the temperature and the constitution of the gas. While a certain amount of theoretical consideration has been given to the calculation of the constants a and b, the state of the theory, especially regarding the constant b, is still in a very unsatisfactory condition. Our knowledge of this constant is chiefly of an empirical character.

By the time the projectile has moved a caliber or so in some guns, we may have a gas pressure as high as 45,000 lbs./in.^{2} or about 3000 atmospheres and the temperature of the gas depending upon the kind of powder, will vary from 2300°

C. up to 3600° C. As a result of our greatly improved knowledge of the equilibrium constants of chemical reactions and of the specific heats of the gas as obtained from band spectra by the aid of quantum mechanics, we are now able to compute with a fair degree of precision the pressure and temperature of the powder gas provided that the chemical constitution of the powder and its heat of formation are known.

You may be interested to learn some of the results of such computations for which the specific heats as tabulated by Lewis and von Elbe have been used. Tables I and II [3] give

TABLE I.

Partial Pressures of the Constituents of Nitrocellulose and Ballistite Powder Gases at a Total Pressure of 340 Atmospheres.

Powder Gas.	Nitrocellulose.	Ballistite.
CO_2	40.92	73.86
CO	138.48	81.04
H_2O	82.00	88.89
H	.84	3.11
OH	1.02	18.99
O_2	—	5.08
H_2	40.69	12.60
O	.01	1.76
N	.01	.17
N_2	36.17	50.84
NO	.06	3.86
Temperature	2663° C.	3398° C.

TABLE II.

Partial Pressures of the Constituents of Nitrocellulose and Ballistite Powder Gases at a Total Pressure of 3400 Atmospheres.

Powder Gas.	Nitrocellulose.	Ballistite.
CO_2	411.0	827.5
CO	1386.5	756.8
H_2O	827.9	964.8
H	2.9	16.1
OH	3.5	133.9
O_2	—	26.0
H_2	407.4	111.2
O	—	7.2
N	—	1.3
N_2	326.6	522.5
NO	.2	34.7
Temperature	2689° C.	3684° C.

[3] The somewhat laborious computations on which these tables are based were made by Miss Good of the Research Division of Aberdeen Proving Ground.

the partial pressures in atmospheres of constituent gases resulting from the burning of two different types of powder under various total pressures. Table I shows the partial pressure in atmospheres of the various gases obtained from the two kinds of powder when the total pressure is 340 atmospheres. Table II gives similar results for the two different kinds of powder when the total pressure is 3400 atmospheres.

It is interesting to note that for the colder powder, which is made up almost entirely of nitrocellulose, the gases obtained are chiefly the well known gases, carbon dioxide, carbon monoxide, steam, hydrogen and nitrogen. On the other hand the hotter powder the ballistite containing about 60 per cent. nitroglycerin, at the low pressure of 340 atmospheres, contains very appreciable amounts of atomic hydrogen, hydroxyl gas, OH, molecular oxygen and nitric oxide. You may see that as the pressure is increased to 3400 atmospheres there is an appreciable change in the constitution, the proportions of the dissociated gases becoming less, as would be expected.

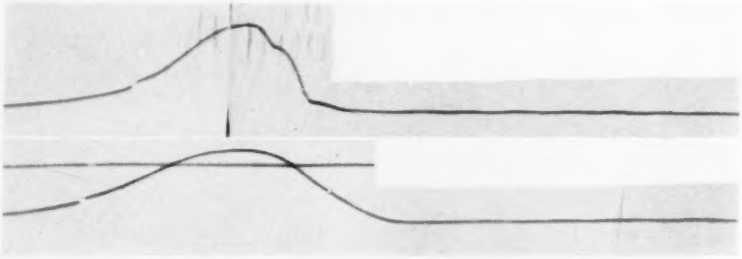
The powders, the gaseous constitution of which are given in the two tables have been fired by Crow and Grimshaw of Woolwich Arsenal, England, in an extensive series of closed chamber experiments, that is, experiments in which the powder is burned in a vessel without doing any external work. Crow and Grimshaw measured the pressures obtained with these powders in chambers of two different sizes in order that corrections might be made for the cooling of the gas during the time the powder is burning. If the pressures as measured by Crow and Grimshaw are corrected for cooling, the pressures thus obtained differ by only about 2 per cent. from those calculated by means of the equilibrium constants and specific heats obtained from the band spectra. In view of the fact that there is a good deal of error in obtaining the cooling corrections and that there is some uncertainty about the heats of formation of nitrocellulose and nitroglycerin, the agreement between the observed and computed pressures is quite as satisfactory as could be hoped for.

Figure 2 shows the pressures developed in the chamber of a 155 mm. gun G.P.F. The records were obtained by means of a piezo-electric gauge, a device invented by Sir J. J. Thomson in 1917 and used at Aberdeen Proving Ground for many

years, and a cathode ray oscillograph. As you will see the upper pressure-time curve is not smooth. There is evidence of waves in the gas, which move forwards and backwards, being reflected from the breech and the projectile. These pressure waves in the gun may be compared to the knock in a gasoline engine. By a suitable design of the charge and ignition it is possible to eliminate the pressure waves in the gun just as it is possible to eliminate the knock in the engine by a change in the fuel.

The lower oscillogram is a record of the pressure in the same 155 mm gun but with a different design of the powder charge. You may see that with this arrangement of charge the pressure waves have been eliminated and a smooth curve is obtained.

FIG. 2.



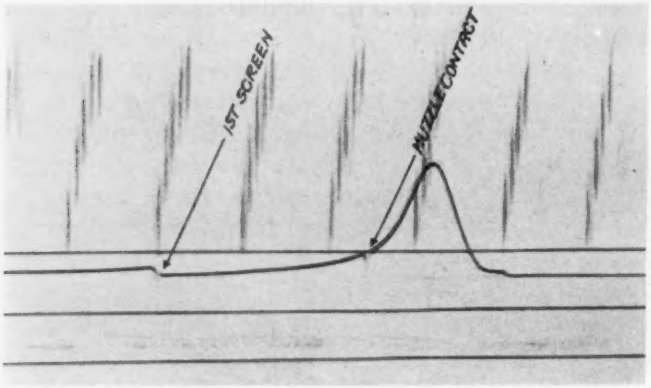
p vs. t. 155 mm.—waves.
155 mm.—no waves.

As a result of the very considerable pressures applied to its base, the projectile accelerates even more rapidly than the modern automobile and soon reaches the muzzle. If there were more time I should like to explain how approximate differential equations for the motion may be obtained, the integrals of which give the velocity and the travel as functions of the time; but the problem of the motion of the gas especially is a most complicated one. Although important contributions to it have been made by Lagrange, Gossot and Liouville, Love and Pidduck and others, much remains to be done.

Figure 3 shows the pressure-time relation obtained in a Springfield rifle caliber .30. You may see from the rather faint timing lines on the film that the entire interval from the

start of the rise of the pressure to the departure of the bullet from the muzzle, indicated by the break in the curve, consumes only a little over one thousandth of a second. From the pressures given by this oscillogram, by the use of a more or less approximate theory concerning the motion of the charge, the friction of the gas and the bullet, the velocity and travel of the bullet have been computed as a function of the time. The results are shown in Fig. 4. A combination of the original pressure-time curve and the travel-time curve provide the pressure-travel curve which is shown in Fig. 5.

FIG. 3.



Pressure vs. Time—Cal. .30 Mod. 1903.

The muzzle velocity obtained with the Springfield rifle is about 2600 ft./sec. As you doubtless know, much higher velocities are obtained with some guns. I understand that the German gun which shelled Paris had a muzzle velocity of about 5,000 ft./sec., while velocities as high as 4800 ft./sec. have been obtained with a small Gerlich rifle having a tapering bore.

THE MAXIMUM THEORETICAL VELOCITY OF A GUN.

You may be interested in knowing the maximum theoretical velocity that could be obtained from a gun of infinite length and a projectile the mass of which is negligible compared to the mass of the charge. Calculations by the method

FIG. 4.

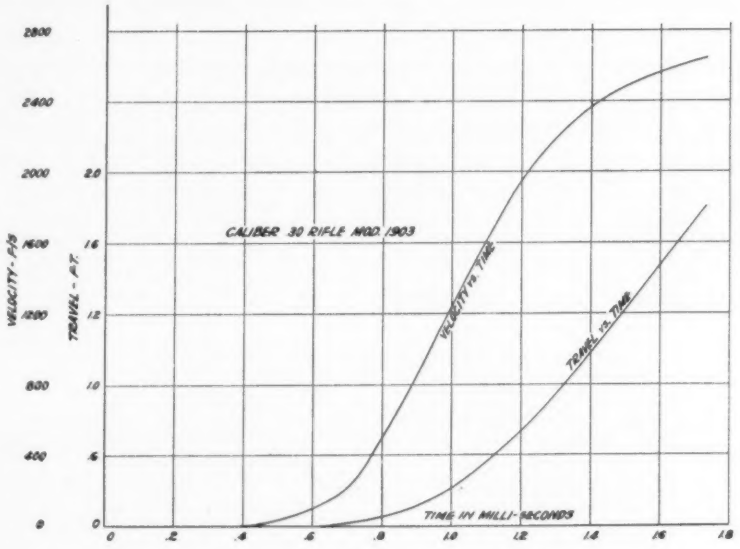
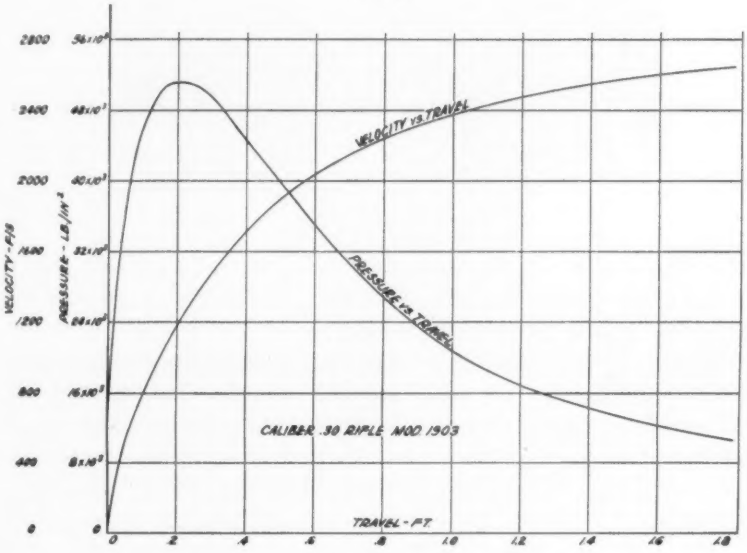
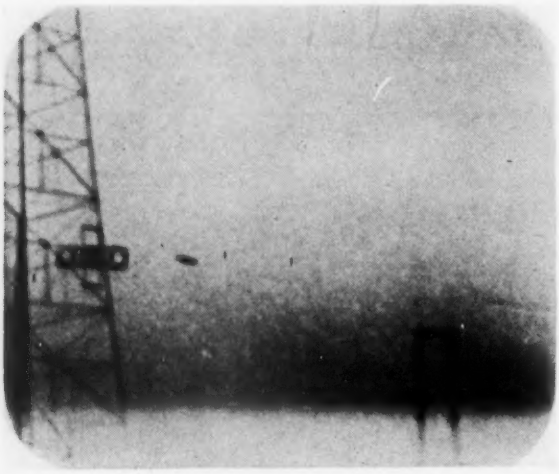

2800
2400
2000
1600
1200
800
400
0
VELOCITY - F/S
2.0
1.6
1.2
1.0
.6
0
TRAVEL - FT.
CALIBER 30 RIFLE MOD. 1903
VELOCITY VS. TIME
TRAVEL VS. TIME
TIME IN MILLI-SECONDS
0
.2
.4
.6
.8
1.0
1.2
1.4
1.6
1.8

FIG. 5.


2800
2400
2000
1600
1200
800
400
0
VELOCITY - F/S
PRESSURE - LB./in.²
VELOCITY VS. TRAVEL
PRESSURE VS. TRAVEL
CALIBER .30 RIFLE MOD. 1903
TRAVEL - FT.
0
.2
.4
.6
.8
1.0
1.2
1.4
1.6
1.8

of H. Lorenz, with important refinements, indicate that the maximum obtainable velocity for the hot ballistite powder is approximately 31,000 ft./sec., while for the cooler nitrocellulose powder, the maximum velocity is about 26,000 ft./sec. Of course these calculations assume absence of waves, neglect the friction effects and heat losses in the bore and also neglect the mass of the air which would be propelled in front of the projectile. It therefore follows that to obtain this velocity one would have to have an infinitely long gun the bore of which would be perfectly reflecting and non-conducting, a

FIG. 6.



Velocity Measurement.

projectile which has no mass and there must be no friction of the gas or projectile in the bore. Besides the air in front of the projectile would have to be exhausted.

I have discussed the motion of the projectile in the bore and the velocity it may attain at the muzzle. Although the projectile emerges with such great speed, let us, Joshua-like, command it to stand still in front of the muzzle while it gets its picture taken. Fig. 6 is a photograph of a 16 in. projectile moving at a velocity of about 2800 ft./sec. taken some years ago by Mr. Jewell of the Proving Ground with the Rumpff high speed motion picture camera. You may see the projec-

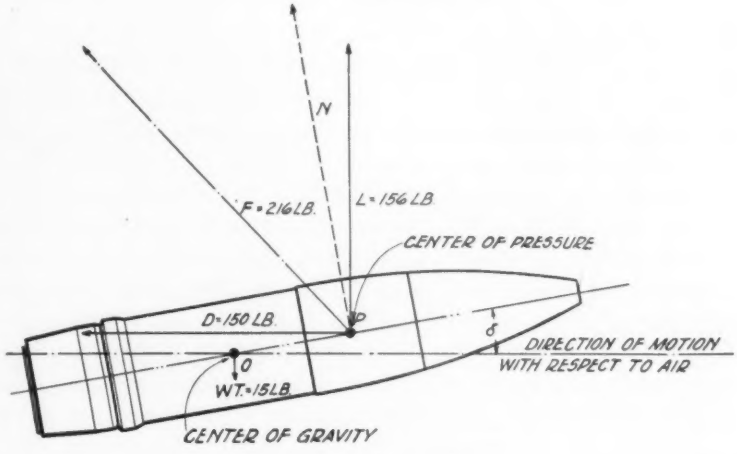
tile approaching coils of wire in which it induces the electromotive forces that provide a measurement of its velocity.

THE FLIGHT IN THE AIR.

Let us now consider the motion outside the muzzle.

During the time the projectile was in the bore it had been given an angular acceleration by the torque imposed on it by the twisting lands of the gun. As a result of the spin thus produced centrifugal forces were developed which caused the projectile to be cocked in the bore. When it reached the muzzle the axis of the projectile did not exactly coincide with

FIG. 7.



Forces acting on projectile.

the axis of the bore. We say that the projectile left the muzzle with a certain initial yaw, which is defined as the angle between the tangent to the trajectory and the axis of the projectile. As the muzzle blast moves by the projectile, it is given a somewhat greater velocity and there is also perhaps a tendency to augment slightly the yaw produced by the centrifugal action in the bore. When the projectile finally gets out into the still air, as a result of its high velocity, considerable air forces are exerted upon it by the atmosphere in

which it moves. Fig. 7 shows the forces acting on a 75 mm. projectile at a velocity of about 2200 ft./sec., the angle of yaw of the projectile being about 10°. Because of the oblique presentation of the projectile the line of action of the resultant air force makes an appreciable angle with the trajectory. Since its point of application is ahead of the center of gravity of the projectile, the air force tends to overturn the projectile and unless the projectile has the required spin it will overturn.

You may like to know how the air forces acting on a projectile moving at velocities as high as 4000 ft./sec. or more are measured. The head resistance or drag was first measured in 1741 by the Englishman Robins. He measured the drop in velocity between two points along the trajectory. From this drop the drag is easily deduced. The component of the force perpendicular to the trajectory, called the cross wind force, was first measured by the well-known physicist R. H. Fowler at Portsmouth England in 1918 by an analysis of the recorded oscillations of two projectiles having the same shape and size but different positions of the center of gravity.

I shall not bore you with the details of the theory of the motion of the projectile about its center of gravity and the stability of its motion. I merely recall to you the fact that the theory of the stability of the projectile is very similar to the theory of the stability of the top. As you all know if a top is not spun sharply enough, it will topple over. Similarly if a projectile is not given a sufficiently great spin, it also will tumble producing a very erratic flight. Of course, if we fire projectiles which tumble, the dispersion in range and direction will be enormous and there will be little chance of hitting the target.

As a result of the yaw of the projectile when it is launched into the atmosphere, the projectile wobbles with an amplitude depending upon its initial yaw, the angular velocity of yaw, the moments of inertia and the magnitude of the air moment. Fortunately, however, just as the top goes to sleep about the vertical when spun on a table the projectile tends to go to sleep on its trajectory. If it did not go to sleep in this way, the range obtained from ordinary projectiles would be very appreciably reduced. There is a theoretical possibility that

instead of the projectile going to sleep, the yaw may become larger and larger as it moves along the trajectory. Experimentally, projectiles of this type have been fired and observed.

During the time the wobbling is being damped out the trajectory itself is being curved by gravity. As a result of this action, the projectile begins to point somewhat above the trajectory, ordinary gyroscopic action takes place and the nose of the projectile precesses towards the right of the trajectory. The projectile, yaws to the right and an air force pushes it to the right. This right pointing of the projectile and the air force impressed upon it as a consequence cause the well known right drift of projectiles fired from guns with right handed twists.

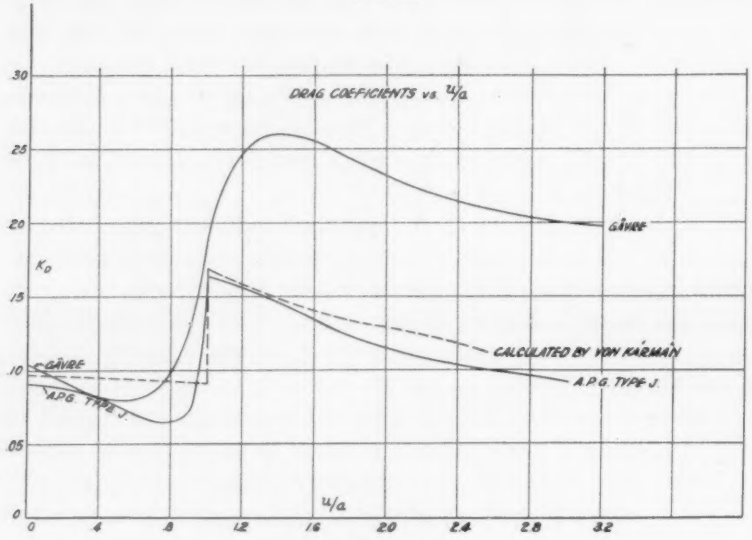
For most trajectories, the precessional yaw due to the gyroscopic effect is small. The projectile may be considered as moving nose on. If the air resistance of the projectile when moving nose on is known as dependent upon the velocity and the air density, then aside from the drift the trajectory may be calculated.

Figure 8 shows the drag or head resistance coefficient of the old fashioned two caliber radius of head projectile with a flat base. To obtain the actual head resistance or drag of this projectile, the resistance coefficient must be multiplied by the density of the air, the square of the diameter of the projectile and the square of the velocity with respect to the air. Fig. 8 also shows the drag coefficient of another projectile (type J) of a more modern design having a long point and a boat-tailed base, that is to say the base is in the form of a truncated cone. The comparison of the two curves shows what a great reduction in air resistance is obtained by the better shape of the more modern projectile. It is obvious that, other things being equal, the more modern type would have a much greater range.

In the same figure is also shown the drag coefficient of a long pointed flat-based projectile calculated by von Kármán. In view of the difference in shape between the type J projectile and von Kármán's projectile, the similarity between the two curves is rather striking. It makes us hope that such theoretical results will be of considerable practical value in connection with projectile design.

If we have two projectiles of the same shape moving at the same velocity, it is plausible to assume, and there is experimental evidence to back up the assumption, that the air forces acting on the projectiles are proportional to the squares of the diameters. Since the acceleration is the ratio of the

FIG. 8.



Drag coefficients.

force to the mass, it follows that if we have two projectiles of the same shape moving at the same velocity in air of the same density the retardations should be inversely proportional to the values of

$$\frac{m}{d^2},$$

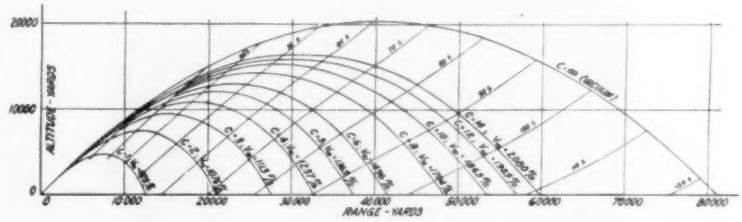
where m is the mass and d the diameter.

A special name is given to the quantity m/d^2. It is called the ballistic coefficient. Other things being equal, the retardation is inversely proportional to it, that is, the greater the ballistic coefficient, the smaller the retardation.

Figure 9 shows trajectories of a number of long pointed boat-tailed projectiles of the same shape but different ballistic

coefficients. The muzzle velocity of each of these projectiles is 2800 ft./sec. There is also shown a trajectory for a shell fired in vacuo. The range of a shell fired in vacuo would be the same as that of one having an infinite ballistic coefficient. It may be seen how much greater range is obtained with a large ballistic coefficient such as would be obtained in a 16 in. or 18 in. projectile than with a small ballistic coefficient as would be obtained for a 3 in. projectile.

FIG. 9.



Trajectories.

Probably some of you have read Mr. Northrup's recent book "Zero to Eighty" in which he describes a stratosphere gun. This book contains no data on the actual velocity required for a projectile to pierce the atmosphere and to have a sufficient remaining velocity to escape the earth's gravitational field. Assume that such a projectile would have the best shape that we have obtained with projectiles in the past, that its mass would be 2000 lbs. and its diameter 15 in. For this projectile to pass through the whole atmosphere and still have enough velocity remaining to escape the earth's gravitational field, that is about 7 mi./sec., the muzzle velocity would have to be about 42,000 ft./sec. or 8 mi./sec.

Mr. Northrup's proposed projectile weighs about 3085 lbs. and its diameter is 45 in. The muzzle of his gun is to be placed on top of Mt. Popocatepetl where the air density is only about one-half as great as at sea-level. The muzzle velocity required for such a projectile to pierce the remaining atmosphere and escape from the earth is calculated to be about 58,000 ft./sec. or 11 mi./sec. It is clear from the

previous discussion that such great velocities as these are beyond the powers of the conventional gun. Perhaps they might be attained by Mr. Northrup's electric gun.

The retardation of Mr. Northrup's projectile due to air resistance would be about 1800 g. at an air speed of 11 mi./sec.

FIG. 10.

Armor penetration.

FIG. 11.

Armor penetration.

a retardation which would be fatal to the occupants. To provide a tolerable retardation, the air force would have to be almost exactly opposed by some propulsive force.

I have discussed briefly the motion of the projectile in the gun and have touched upon certain features of its motion in

the atmosphere. The projectile passes along its trajectory until it finally hits the target. I shall not discuss the subject of the penetration of the target by projectiles but I shall show some photographs of impacts of bullets on an armor plate showing varying amounts of penetration. These spark photographs were taken at Aberdeen Proving Ground by Mr. Ralph Gerdom. Fig. 10 shows two pictures of the bullet. In the first picture the bullet has not yet hit the plate, in the second picture it has penetrated slightly. The pictures of Fig. 11 show greater penetration and the splash of the jacket. The reversal of image is due to the fact that the hot particles caused a second exposure of the film.

Reflectors Promote Highway Safety.—Just as the State of Michigan a quarter of a century or so ago assumed the leadership and became the world center for the manufacture of automobiles, so it has taken the lead in the installation of ultra-modern reflectors on one of its main highways for the promotion of safety in night driving. The installation has been made on U. S. No. 16, an 85-mile stretch of highway from Detroit to Lansing. The new reflectors are a radical departure from those in more general use. They are made of "Lucite" methyl methacrylate, a plastic recently perfected by the duPont Company that is water clear, flexible and non-shattering. This plastic molds much more accurately than glass and retains permanent transparency. It does not change color, but remains stable over a long period. The reflectors are set 100 feet apart on either side of the roadway, except at curves where they are slightly closer. The headlights of an automobile make it possible, as they are thrown on the reflectors, to illuminate the highway sufficiently for night driving. A test of these reflectors was first made by General Motors, because of the company's interest in highway safety, on two or three small stretches of road on the company's proving grounds at Milford, Michigan. There it was found by drivers who test cars at night, as well as during the day, that the reflectors not only acted as an important guide in driving, but that also they relieved eye strain, penetrated fog, and that the glare from the lights of on-coming cars was greatly reduced. This latter is due to the fact that glare, being a matter of relativity, is not so great on an illuminated highway. Importance of the new reflectors to lessen, if not wholly prevent, night accidents is indicated by the fact that sixty per cent. of the fatal accidents in the United States occur after dark and forty-eight per cent. of the personal injury accidents, although only one third of all driving is done during this night period.

R. H. OPPERMANN.

ON THE RÔLE OF TUBE WALLS, AND SURFACE AND SPACE CHARGES IN ELECTRICAL DISCHARGES THROUGH RAREFIED GASES.

BY

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ABSTRACT.

Several matters pertaining to the part played by tube walls, and surface and space charges in electrical discharges through rarefied gases, are briefly discussed, and experiments are described which throw light on some of the processes involved in such discharges. Measurements made under identical conditions of the falls of potential between striæ in the positive columns of discharges in hydrogen at various pressures in two glass tubes of different diameters showed that for pressures above 1.1 mm. these falls were increasingly greater in the larger tube. The results of experiments done with discharges produced under unusual conditions and bearing on the radial and axial fields present in the positive columns of discharges are described, and photographs of some of the discharges are reproduced in a part of which the positive column was made to pass through a long metal tube placed inside of the glass discharge tube, the two ends of the metal tube being at times both open and at other times both closed with wire gauzes of fine mesh. The potential assumed by the metal tube and the current flowing through its walls were measured, and special experiments were done to elucidate the process by which the current manages to penetrate the more or less field-free space inside the metal cylinder. The distributions of the space and surface charges along the length of a glass discharge tube were measured separately, at least roughly, and the nature of these distributions was found to depend markedly upon whether the anode or the cathode of the discharge tube was connected to earth, although the combined effects of the two charges of necessity produced the same field distribution within the discharge tube in both cases. The gases used in the experiments were air and hydrogen.

When a steady electrical current is passing through a rarefied gas contained in a long glass tube of uniform section, the axial field is found to be constant over the whole length of the positive column in the discharge, provided this is not striated. In seeking the origin of this uniform axial field, Ollendorf and Seeliger [1] were led to conclude that it can only be accounted for by the presence of surface charges on the walls of the tube. Similarly, surface charges are always assumed to establish

[1] F. Ollendorf and R. Seeliger, *Phys. Zeits.*, **33**, 577 (1932).

themselves in such a way over the surface of a metallic wire of uniform section which is carrying a steady current as to produce the uniform longitudinal gradient necessary for continuity of electric flow.

The above authors set themselves the simplified problem of finding what the distribution of charge along a long straight discharge tube must be to produce a uniform gradient along its axis. The formula obtained for this distribution calls for a positive charge on one half of the length of the tube and a corresponding negative charge on the other half, both charges diminishing in a given manner from the ends toward the center of the tube. The authors consider this result to be out of harmony with the idea that the charge on the walls is produced by the diffusion of ions to them from the body of the gas and that hence, owing to the far greater speeds acquired by electrons from the field, the charge on the walls should everywhere be negative. They are therefore led to suggest that the conditions in a so-called steady discharge may only appear to be stationary and that the observed uniform gradient may in reality be only an average effect.

That a high frequency intermittence or variation in the current of many discharges does actually exist is now well established, but the procedure of attempting to find the distribution of charges on the walls of a discharge tube by considering diffusion effects alone may well be questioned. The dominant factor in the production of surface charges in a discharge tube, where such charges exist, is not the diffusion process but rather, as with metallic conductors, the impelling necessity of producing a uniform gradient to ensure continuity of current flow. The presence of both kinds of carriers in the gas makes possible any distribution essential for this continuity, and a distribution appropriate for any given boundary conditions is established by the combined action of diffusion and of fields arising from space charges formed during the initial stages of the discharge.

However, the axial field as well as the radial field in a long discharge tube may rather be due in large part to space charges in the gas in the outer portion of the tube, as was maintained especially by Holm.[2] Some experiments will be

[2] R. Holm, *Phys. Zeits.*, **15**, 241, 289, 782 (1914); **16**, 20, 70 (1915). R. Seeliger, *Phys. Zeits.*, **15**, 777 (1914).

described presently which were done under conditions where it is only possible to account for both the large axial and radial fields present on the assumption that they are produced by such space charges. Space charges, when distributed in symmetrical, cylindrical form about the axis of a discharge tube and which diminish in magnitude along the length of the tube, have the same influence on the axial field in the tube as would similar surface charges on its walls.

It is sometimes stated that it is the negative charge initially acquired by the walls of glass discharge tubes from electrons diffusing to them, which, by assisting the motion of the positive ions and retarding that of the electrons moving outward from the body of the discharge, causes the two kinds of charge to flow to the walls at equal rates, after a steady state between these losses and new ions formed by ionization has been reached. Inasmuch as a uniform cylindrical distribution of surface charge produces no appreciable radial or axial field on the inside of the cylinder except near its ends, it is necessary in order to explain such fields by surface charges to postulate in addition a surface density which changes along the length of the cylinder. However, the larger part of the radial component of the field existing at any point, a distance r from the axis of a long discharge tube, doubtless arises from the positive space charge found within a cylindrical volume coaxial with the tube and having the same r for its radius.[3] A positive ion at the point under consideration may thus be looked upon as being pushed toward the wall by a positive charge behind it rather than as being pulled by a negative charge in front of it.

Although owing to refraction effects in glass tubes the positive column often appears to fill the whole cross section of the tubes, nevertheless a more or less non-luminous region is always present near the walls of all discharge tubes, the width of which is larger the smaller the current flowing. The speeds of any electrons present in this region must be insufficient to produce the excited states in the molecules of the gas which are a prerequisite for visible radiation. The space charge in the positive column is usually supposed to be confined mainly to this non-luminous region, but Salinger [4]

[3] J. S. E. Townsend, *Phil. Mag.*, **11**, 1114 (1931).

[4] H. Salinger, *Ann d. Physik*, **54**, 296 (1917).

found that in any cross section of a striated column in a glass discharge tube the potential in the gas increases from the walls clear to the axis of the tube, bespeaking a charge throughout the whole space, although its density is much smaller near the axis than in the outer regions. Evidently, if the axial field is uniform in an unstriated positive column there can then be no space charge in this axial region.

Salinger found that the potential difference between the gas on the axis of a tube and that near its wall decreased perceptibly in going from the anode end of the positive column toward the cathode, which may be taken as evidence that the axial field in the column is determined, at least partly, by space charges in the tube. It must not be assumed that the axial current in the positive column is confined wholly to the luminous region, for the axial component of the field in the non-luminous space near the walls is usually larger than the radial component and as a rule both electrons and positive ions are present in this space.

That the walls of glass tubes have a large influence on discharges through them is well known. There may be some question as to how much of this influence is due to charges which gather on the walls and how much to the space limitations imposed by these walls on the discharge, as affecting, for example, the rate at which ions are lost from the discharge path by diffusion.

It is often noticed on applying not too high a voltage to a discharge tube that only a momentary discharge flashes through the tube. The stoppage of the current might be ascribed to the effect of charges which have gathered on the walls of the tube, but the stoppage may be a result of polarization of the electrodes by ions which are kept from discharging to the surface by an interposing layer of gas that is adhering to the surface.[5]

When the gas pressure in a tube is well below 1 mm., the discharge in a tube is not easily affected by charged bodies placed near it. Thus a tube 2 cm. in diameter and 40 cm. long, in which the striæ in the positive column were about 1 cm. apart, could be wrapped for 30 cm. with tin-foil without

[5] W. Gaede, *Ann d. Physik*, **14**, 641 (1904). J. Zeleny, *Phys. Rev.*, **16**, 102 (1920); **19**, 566 (1922).

affecting appreciably any characteristic feature of the discharge even when the tin-foil was connected to either the anode or the cathode of the tube. When the pressure of the air was several millimeters in a similar tube the unstriated positive column was readily attracted by any earthed object brought near to it. With a tube 2.6 cm. in diameter containing hydrogen at a pressure of 2.3 mm. no noticeable effect on the discharge was produced by bringing up to it a highly charged piece of sealing wax or by touching the outside of the tube with the hand, except when the current was reduced to about 1 m.a., a value near the limit at which the discharge could be maintained. Near that limit, either of the above procedures might stop the current or start it again after it had been interrupted. Above these limiting currents the charges within the tube had a rigid control over the fields which prevailed there.

Lehmann [6] found that the positive column was always absent from discharges in vessels of large diameter, and Gehrcke [7] showed that the distances between striæ in the positive column are widely different in tubes of different diameters when currents of the same density are used.

FALL OF POTENTIAL BETWEEN STRIÆ IN TUBES HAVING DIFFERENT DIAMETERS.

Some measurements made of the fall of potential between adjacent striæ also showed as a rule a marked dependence of this significant quantity upon the diameter of the discharge tube. The gas used was hydrogen and the method of finding the fall of potential between the striæ was that previously described.[8] Two discharge tubes having internal diameters of 7.0 mm. and 12.4 mm. and sealed in parallel into a vacuum system were employed, and the currents used in them during the measurements were 2.1 m.a. (milliamperes) and 6.6 m.a., respectively, these numbers making the average current densities the same in the two tubes. For pressures below 1 mm. of mercury the falls of potential between striæ in the two tubes were found to be nearly the same, being 12.7 volts

[6] O. Lehmann, *Ann. d. Physik*, **7**, 1 (1902).
[7] E. Gehrcke, *Ann. d. Physik*, **15**, 509 (1904).
[8] J. Zeleny, JOUR. FRANK. INST., **209**, 629 (1930).

and 12.5 volts, respectively, for the large and small tubes. As the pressure was raised above 1.1 mm. the two values both became larger and the difference between them increased rapidly so that at a pressure of 2.73 mm. the two values were 26.0 volts and 22.0 volts, respectively. These potential falls all diminished when the current was increased.

The average axial potential gradients observed in the positive columns of the two tubes, when the currents indicated above were used in them, were found to be 22.6 and 29.4 volts per cm. for the large and small tubes respectively at a pressure of 0.70 mm., and 38.2 and 51.0 volts per cm. at a pressure of 2.73 mm.

Qualitatively at least, the manner of variation of these different quantities is understandable. Thus, when a tube has a smaller diameter the loss of ions and electrons to its walls is proportionately greater than it is in a larger tube and hence to replenish this greater loss a larger potential gradient is required in the smaller tube, as was found to be the case. In the larger potential gradient in the smaller tube the electrons can acquire the energy requisite for ionizing molecules after fewer free paths of their motion and accordingly, as experiment shows, the striæ in smaller tubes are found to be closer together than in larger tubes at the same gas pressure. Again, the losses of energy by electrons during elastic impacts with molecules in going through the distance between two striæ are quite small in both tubes at the lower of the two pressures named [8] and here the potential falls between two adjacent striæ in the two tubes were found to be nearly identical, whereas at the higher of the two pressures where these losses became significant the potential fall between striæ was larger in the larger tube where owing to the smaller gradient present a larger number of collisions was involved than in the smaller tube.

The increase in the falls of potential between striæ with increase in gas pressure that was found in both tubes might be ascribed to the greater energy losses suffered by electrons at the higher pressures during the elastic collisions just described, but when allowance is made for such losses by use of a formula given by Compton [9] the corrected values still

[9] K T. Compton, *Phys. Rev.*, **22**, 339 (1923).

increase with pressure.[8] However, Townsend and Bailey [10] presented evidence from which they concluded that during collision with molecules electrons actually lose more of their energy than is computed on the assumption of a purely elastic collision of spheres on the sole basis of which Compton's formula was derived.

DISCHARGES THROUGH TUBES WITH CONDUCTING WALLS.

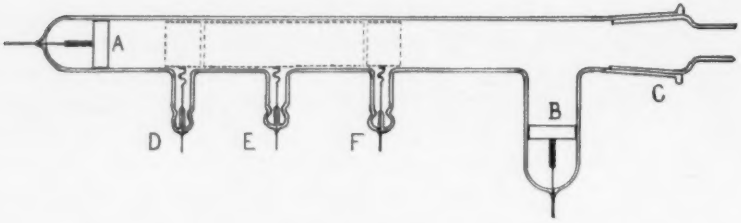
Gehrcke [7] made the interesting observation that when a portion of a discharge tube was covered on the inside with a transparent coating of silver the discharge went through this portion practically unchanged and the distances between the striæ in the positive column were nearly the same in the coated part as in the uncoated portion; but when a coating of phosphoric acid was used the distances between the striæ were reduced to less than half of their former value. When a thick coating of silver covering but half of the circumference of the tube was used the striæ were pushed from the center of the tube toward the unsilvered side and the stria distances were again much smaller. Holm [2] performed a somewhat similar experiment in which an aluminum tube was slid partly over the anode without touching it. The positive column was found to pass directly through the insulated metal tube but the diameter of the column inside the tube was smaller than in the portion outside of the tube and the striæ inside the tube were closer together than those outside. In these experiments charges in the gas, and more especially those near the metal walls, must shield the path of the discharge from the influence of the equipotential walls and make possible the large axial gradient that prevails. This is the explanation given by Holm who maintains that even in glass discharge tubes charges on the walls play a subordinate part.

The experiments which are now to be described also deal with the passage of discharges through metal tubes placed in the region of the positive column and so are an extension of the work previously done by Gehrcke and Holm. The glass discharge tubes used were of the form shown in Fig. 1 and had an internal diameter of 2.2 cm. The anode A and the

[10] J. S. E. Townsend and V. A. Bailey, *Phil. Mag.*, **42**, 873 (1921).

cathode *B* were made of aluminum. As made, *B* should actually point into the paper. *C* is a ground glass joint which permitted various objects to be placed into the path of the discharge. The auxiliary electrodes *D*, *E*, and *F* are here shown connected to three gauze cylinders and they made possible the measurement of the potentials these cylinders assumed when insulated, and of the currents flowing between them when they were metallically joined together through ammeters. Other tubes with but one and two such electrodes were also used. The metallic cylindrical tubes used were made of fine-meshed brass gauze to make observation and photography of the luminous effects within easily possible, the spacings in the gauze being 0.3 mm., of which the wires themselves covered one half. A high potential storage battery

FIG. 1.



was used as a source of potential and a liquid resistance was placed in series for regulating the current. Unless otherwise stated, the gas used in the experiments to be described was hydrogen. The positive column in the discharges studied was usually striated, and while this fact gives an added complexity to the phenomena, it is advantageous in that it makes possible an estimation of the distribution of potential along the axis of the column on which much of the interest centers.

Reproductions of a few of the photographs taken of discharges produced under various conditions are shown in Figs. 2 and 3. The lens of the Leica camera which was used was located for Fig. 2, 33 cm. above, and for Fig. 3, 43 cm. above a point on the axis of tube situated 8 cm. from the anode. The exposure times varied between 1 and 3 seconds. The anode end of the discharge tube is always shown at the

left side of the figures, and the cathode end usually does not appear. The notation on the figures gives the gas pressure p in millimeters of mercury, V the voltage across the discharge tube, I the total discharge current in milliamperes, v_1, v_2 and v_3 the potentials below that of the anode of any gauze cylinders in the tube in their order from the anode, and i_1 and i_2 the currents between these cylinders when measured. Photographs taken of scales placed transversely on a diametrical plane inside of the tube showed that the foreshortening on the photographs arising from refraction effects in the glass walls of the tube were insignificant up to 6 mm. from the axis of the tube. At 10 mm. from the center the total foreshortening at no part of the tube exceeded 0.3 mm. For the outermost millimeter the error could not be determined from the photographs taken.

A characteristic form of the striated positive column, when passing through an insulated gauze cylinder 11 cm. long, placed 1.2 cm. from the anode, is shown in Fig. 2*a*. The main noteworthy feature not previously reported is that while the width of the stria at the right-hand end of the cylinder is nearly equal to the diameter of the cylinder itself, the other striæ are progressively of smaller diameter and are crowded closer and closer together as the left or anode end of the cylinder is approached. The appearance is such as would be expected for a discharge passing through a glass tube which is narrower at the anode end than it is at the other end.

The diameter of the positive column within the metal cylinder is markedly dependent upon the magnitude of the current passing, being larger the greater the current. This is illustrated by Figs. 3*a* and 3*b*, for both of which the experimental conditions were identical except that in the first figure the current used was 3 m.a. and in the second it was 20 m.a. The gauze cylinder here consisted of two parts, each 8 cm. long, placed 5 mm. apart but metallically connected through a milliammeter. The striæ with the lesser current have everywhere a smaller diameter than corresponding striæ with the larger current. However, there appears to be a minimum width for the positive column below which a discharge cannot be maintained, and accordingly for very small currents the positive column is narrow and nearly of the same width

throughout the whole portion of that part of its path which lies within the metal cylinder.

The appearance of a discharge when passing through two insulated gauze cylinders placed in its path is shown in Fig. 3*c*. The potentials assumed by the two cylinders were, in their order from the anode, 330 volts and 532 volts, respectively, below that of the anode. The striæ increase in diameter from left to right in each cylinder, and doubtless for the same reason as will be given directly for the case where but one cylinder was present.

The axial fields required to maintain these discharges inside a metal tube cannot arise from charges on the surface of the tube since this is essentially an equipotential surface; and only a small contribution can be ascribed to charges on the electrodes themselves and to other charges present outside of this metal tube. The main axial component of the field within the gauze cylinder, aside from local variations within a stria distance which are caused by local variations of space charge, must rather be due to an excess of positive ions in the peripheral portions of the discharge itself. Judging from the number of striæ within the cylinder in the figures shown, the total fall of potential along the length of the cylinder must be over 200 volts. From the fact that the stria at the end of cylinder nearest to the cathode almost fills its whole diameter and from some potential measurements which were made, it appears that the insulated cylinder assumes approximately the same potential as obtains in the gas just outside of its cathode end. At the anode end of the cylinder, therefore, there must be a difference of potential of over 200 volts between the cylinder and the gas near its axis. This large difference of potential forms so great a potential barrier for electrons that here, and indeed over the larger portion of the length of the cylinder, no electrons are able to get by diffusion from the body of the discharge to the walls, since the maximum energy attained by them rarely exceeds that required for ionization, i.e. about 16 electron-volts. On the other hand the positive ions which diffuse from the discharge path are urged toward the wall by the radial field which their presence helps to maintain. Electrons that are liberated at the walls of the cylinder by the impact of positive ions are

FIG. 2.

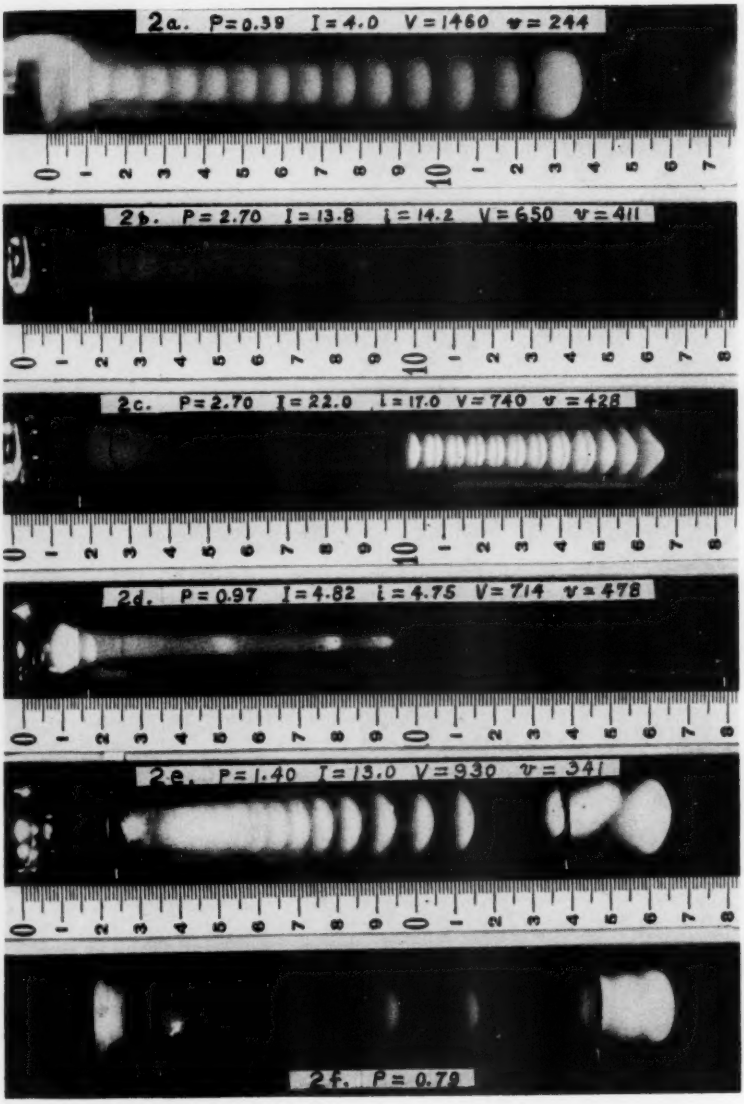
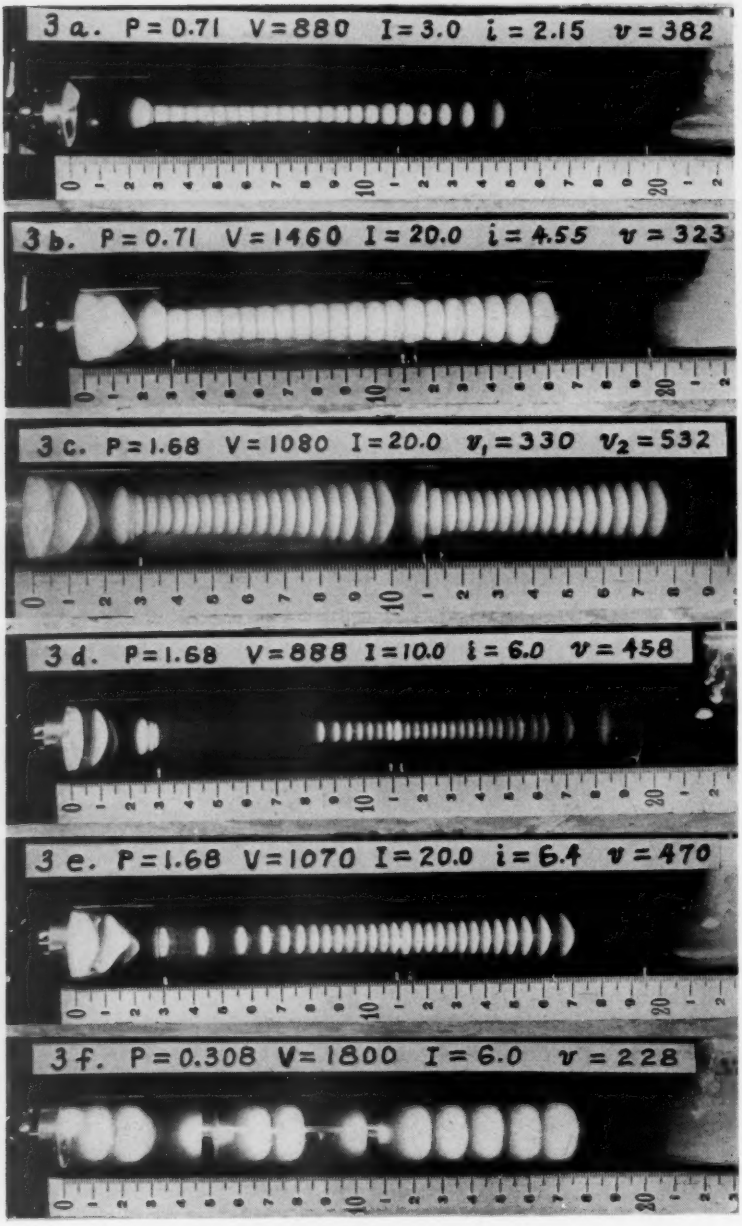

2a. P=0.39 I=4.0 V=1460 v=244
2b. P=2.70 I=13.8 i=14.2 V=650 v=411
2c. P=2.70 I=22.0 i=17.0 V=740 v=428
2d. P=0.97 I=4.82 i=4.75 V=714 v=478
2e. P=1.40 I=13.0 V=930 v=341
2f. P=0.79

FIG. 3.


3 a. P = 0.71 V = 880 I = 3.0 i = 2.15 v = 382
3 b. P = 0.71 V = 1460 I = 20.0 i = 4.55 v = 323
3 c. P = 1.68 V = 1080 I = 20.0 v1 = 330 v2 = 532
3 d. P = 1.68 V = 888 I = 10.0 i = 6.0 v = 458
3 e. P = 1.68 V = 1070 I = 20.0 i = 6.4 v = 470
3 f. P = 0.308 V = 1800 I = 6.0 v = 228

naturally aided by the radial field in their migration toward the axis of the tube.

As the cylinder is insulated and maintains a constant potential, the charge constantly received by it from the positive ions must be neutralized somewhere by a flow of negative electrons to it. This flow must take place near the end closest to the cathode where the cylinder is approximately at the potential of the adjacent gas. There must therefore be a current constantly flowing along the length of the cylinder from the end nearest the anode towards the cathode end. This current could be measured by the arrangement used for the discharges shown in Figs. 3*a* and 3*b* where the cylinder was divided into two parts each of which was connected to one terminal of an insulated milliammeter, the current through which is indicated on the figures by *i*. For a discharge current of 3 m.a. the current between the two portions of the cylinder was 2.15 m.a., and this rose to 4.55 m.a. when the main discharge current was increased to 20 m.a. The smaller the main current the larger, relatively, is the wall current, i.e. the larger is the fraction of the ions lost by the discharge path to the walls of the cylinder.

The magnitude and distribution of the wall currents is illustrated further by the data given in Table 1, obtained

TABLE 1.

Voltage Across Tube.	Voltage of *D*, *E*, *F*	Total Current.	Current *D* to *E*.	Current *E* to *F*.
1077	415	13 m.a.	0.83 m.a.	2.55 m.a.
1057	442	10	.74	2.30
1001	457.5	7	.66	2.00
950	468	5	.63	1.80
893	473	3	.58	1.45

with a gauze cylinder divided into three parts, as shown in Fig. 1, the currents between which were measured by insulated milliammeters placed across the two gaps between them. The part *D* was 1.55 cm. long and was 2.5 cm. distant from the anode. The middle portion *E* was 7.2 cm. long and was separated from the others by 2.5 mm. gaps. The length of *F* was 1.5 cm. The pressure of the hydrogen in the tube was 1.27 mm., and the striated positive column passed through

and beyond all three sections. The magnitudes of the common potentials given for *D*, *E* and *F* are the amounts these potentials were below that of the anode. With an increase of pressure the wall currents become smaller, relative to the main current. At another time when the gas pressure was nearly the same as that above, the three portions of the cylinder while insulated from one another assumed potentials relative to the anode of 201, 405 and 469 volts respectively, in the order *D*, *E* and *F*, when the discharge current was 4 m.a. and the total voltage across the tube was 861 volts.

For the largest discharge current used, the diffusion current flowing to *D* is seen to be 6.4 per cent. of the main current and that flowing to both *D* and *E* is nearly 20 per cent. of the main current. The latter value increased to nearly 50 per cent. when the main current was reduced to 3 m.a. The proportionate losses to the walls are thus seen here too to get larger as the discharge current becomes smaller. With still smaller currents the end of the positive column contracts toward the anode and below a certain value a current through the cylinder can no longer be maintained.

As the main current is reduced the positive column everywhere decreases in diameter and the striæ get closer and closer together. The smaller positive ion density in the positive column for the smaller currents calls for a thicker positive ion sheath near the walls to keep up the requisite potential difference between the two, and the smaller distance between the striæ bespeaks a greater potential gradient which enables each of the fewer electrons in the current stream to produce by impact a greater number of ions per unit length of the tube. Both of these factors thus help to maintain the discharge. As the current is reduced a value is eventually reached for which the number of positive ions striking the cathode is not sufficient to produce there the necessary continuous supply of electrons, and the discharge ceases to flow.

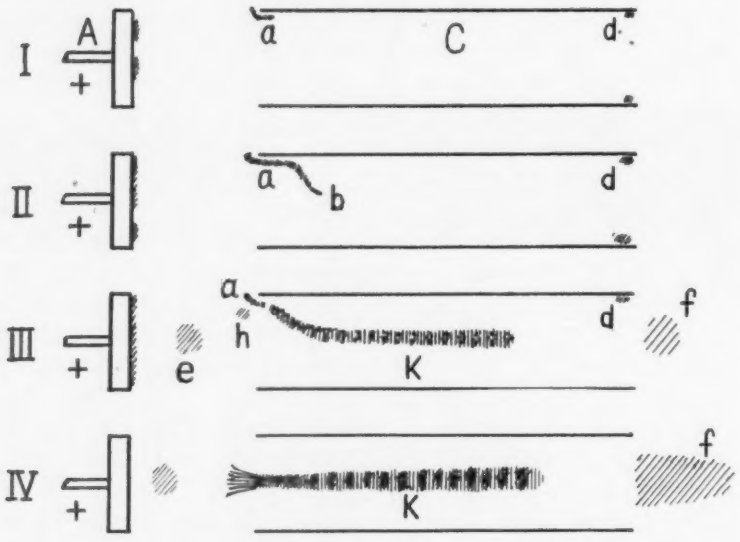
The decrease in the diameter of the positive column inside of the metal cylinder from its end facing the cathode to the end facing the anode, and the attendant decrease in the distance between the striæ, for any given current, may be explained in the same general terms. The greater difference

in potential between the discharge path and the wall of the tube at the anode end of the cylinder calls for a thicker positive ion sheath at this place and hence a narrowing of the positive column. The diffusion loss of ions at this place must now be supplied by a smaller volume and this is made possible by the larger potential gradient found there, which serves to increase the number of ions each electron produces per unit length of the tube.

Some light on how the conducting path along the axis of the gauze cylinder is first produced by the discharge was obtained from observations made at gas pressures under which the different stages in the process appeared in sequence as the current through the tube was increased by suitable steps. One set of such observations will be described where the gas used was air at a pressure of 1.76 mm., and where a gauze cylinder 8.5 cm. long was placed in the discharge tube with one end 2.9 cm. from the anode. The voltage across the tube varied but little from 1070 volts for the different stages of the discharge that will be considered. The main features of the discharge for four different currents are shown in Fig. 4, where the anode *A* and the gauze cylinder *C* are alone indicated in section. In I the current of 1.3 m.a. all flowed from the anode to the near end of the cylinder through the negative glow "*a*," and then out again from the other end at "*d*" to the cathode, which is not shown. There were thus two separate discharges in series through the gas and the current had to overcome two cathode and two anode falls of potential in its passage through the tube. That no appreciable current here flowed through the gas at the central portion of the cylinder was shown by another similar set-up in which however the cylinder was divided transversely into two equal parts that were connected together through an insulated milliammeter. The current indicated by this instrument was the same as that in the main circuit. The current through the negative glow "*a*" evidently had the so-called "normal" density since the area of the glow varied, at least approximately, directly as the total current. In II the current had increased to 4 m.a. The area of the glow "*a*" was now about three times its former value, and a small tongue of light "*b*" curved out from the glow toward the

axis of the tube. As yet no current flowed down the tube through the gas. At this stage a small increase of current to 4.5 m.a. suddenly produced a marked change, and the appearance became that shown in III, where a well formed striated positive column "*k*" is seen, in which however the striæ were somewhat hazy owing probably to an unsteadiness in the discharge. At the appearance of this positive column the negative glow "*a*" contracted to a small fraction of its previous area and the glow "*d*" also decreased in intensity, showing that only a minor fraction of the total current now

FIG. 4.



flowed by the metallic path and that most of it went down the center of the cylinder through the gas. A glow "*f*" also made its appearance outside of the right end of the cylinder, and two smaller patches of light "*e*" and "*h*" at the left end of the cylinder. With increase of current, "*e*" and "*h*" grew both in brightness and volume and finally the two suddenly blended together, the glows "*a*" and "*d*" disappeared completely, and the positive column assumed the symmetrical axial position "*k*" shown in IV. The whole of the main current now passed through the center of the gauze

cylinder by way of the positive column. The division of the current into two parts, as in III, is apparently found possible when the fall of potential in the portion of it which passes through the gas in the cylinder is equal to the falls of potential at the two surfaces of the metal cylinder which have to be overcome by that part of the current which flows by the metallic path.

The succession of changes in the appearance of a discharge with changes in the current, shown in Fig. 4, is also observed under like conditions when a metal rod of small diameter is simply laid inside of the glass discharge tube in place of the metal cylinder. Presumably, under conditions where the succession of stages described above is not observed, the discharge nevertheless passes through something like the same stages during the exceedingly short time in which the discharge current grows to its steady state.

It should be said that the negative glow, which was described as forming a patch of light on the inner surface of the end of the gauze cylinder, may under other circumstances spread over the whole circumference forming a hollow cylinder that may extend several centimeters down the tube. This is illustrated by Fig. 2*b*, where the gauze cylinder used was 16 cm. long. Starting with a short button at the end of the cylinder when the current was small, the negative glow has here, where the current was 14 m.a., penetrated to a distance of 7 cm. The discharge current all flows through the glow to the walls of the cylinder and normally would pass through the gas from the other end of the cylinder to the cathode. Here however the cylinder was connected directly to the cathode through a milliammeter and a high liquid resistance for the purpose of maintaining the cylinder at a different potential than what it automatically assumes. In the figure, v gives the potential of the cylinder relative to the anode and i the current flowing between it and the cathode through the high resistance. With a further increase of the main current to 22 m.a. the appearance changed to that shown in Fig. 2*c*, where a positive column appears, indicating that a portion of the main current now passes through the gas down the axis of the cylinder to the cathode, at whose surface a glow was seen for the first time. The current

through the gas, which was here 5 m.a., increased to 18 m.a. when the total current was raised to 38 m.a., for which current the length of the striated column was only 1.7 cm. longer that it is in Fig. *2c*. The larger portion of the left end of the cylinder thus still contained the unstriated negative glow through which the remainder of the current passed directly to the walls of the cylinder. Figure *2d* shows the appearance of the negative glow within the same cylinder when the gas pressure had been reduced to 0.97 mm. The glow now has a much smaller diameter than before and spots of light or striæ appear at unequal distances along its length, indicating that the axial field here is greater than it was when the higher pressure was used.

It is difficult if not impossible to get the whole discharge current to pass down the axis of a cylinder of this diameter when the cylinder is as long as the one used in these last experiments. This is illustrated by the data shown on Figs. *3d* and *3e*, where the liquid resistance mentioned above was no longer used and where the cylinder consisted of two equal insulated parts which were joined together through an insulated milliammeter. In Fig. *3d* the total current was 10 m.a., of which 6 m.a. went through the milliammeter. Most of this latter current must have passed to the walls of the first half of the combined cylinder from the unstriated glow that occupied the larger portion of it, and then flowed from the second half to the cathode. The appearance of the discharge when the main current was increased to 20 m.a. is shown in Fig. *3e*. The current between the two parts of the cylinder was now 6.4 m.a., and while this is a smaller portion of the total current than before, its magnitude is nevertheless slightly greater so that its total disappearance should not be expected were the main current to be further increased. The contracted glow at the left end of the first part of the cylinder now contains some striæ, showing again that the axial gradient here is greater than it was before. The above glow, in cases like this, can scarcely be called a pure negative glow since the phenomena in it have become complicated by the passage through it of that part of the current which does not flow to the metal wall.

Turning back to Fig. *2b*, the absence of striæ in the long,

cylindrical, negative glow shows that the gas there is in a highly conducting state owing to ionization produced by electrons coming from the walls of the cylinder which here serve as a cathode for the whole discharge current, and the current flowing to the walls from the glow must have the so-called "normal" current density except possibly at the end of the glow. On increasing the current, therefore, by raising the voltage across the discharge tube, it is easier for the added current to get to the walls of the tube by a spreading of the glow forward than it would be for it to pass more directly to the walls through the area already covered by the glow, since an increase of current there would lead to an increase in the potential fall at this surface above the normal value.

This form of discharge, where all of the current passes to the gauze cylinder, eventually becomes unstable when more voltage would be required to send any added current to the cathode by way of the cylinder walls and the high resistance (here about 18,000 ohms) than is required to take it directly by the gaseous path, and the current divides between the two paths as shown in Fig. *2c*. The point where this change takes place is doubtless dependent on the magnitude of the resistance used, on the length of the discharge tube, and on any difference that exists between the cathode falls of potential of the metals used for the cylinder and the main cathode.

In the mechanism of the final breakdown the electrical conditions in the pointed region at the forward end of the negative glow within the cylinder are apparently of fundamental importance, but these are not fully understood. This small region is always somewhat brighter than the rest of the glow, indicating that either more of the electrons coming from the walls pass per unit volume through this advanced axial place or that for some reason the field here is higher than it is in neighboring regions. Lines of force that leave the front end of the glow, which may here be looked upon as a conducting rod thrust into the gauze cylinder, go for a short distance in the axial direction before curving in toward the walls. As the glow advances down the tube the axial field at its end may even be enhanced more and more by

lines from the cathode which enter the open end of the cylinder. Electrons must enter this tip region of the glow from the walls of the cylinder ahead of the glow, after liberation by positive ions which got there from the glow by following the lines of force. Eventually, by the increased activity of these electrons, the conductivity here is somehow increased to such an extent that the glow region advances progressively and the breakdown noted in Fig. 2*c* takes place.

It may be of some interest merely to indicate by the few data given in Table 2 the changes produced in the discharge

TABLE 2.

	V	v	I	i_1	i_2	i_3
I.....	830	494	4.0	0.57	1.5	0 or open
II.....	695	286	4.0	1.03	3.3	+3.15
III.....	875	552	4.0	0.52	1.3	−2.0

characteristics and in the wall currents in the gauze cylinder by maintaining this cylinder at potentials other than that which it assumes of itself, by an auxiliary battery placed between it and the cathode of the tube. The arrangement of three gauze cylinders shown in Fig. 1 was used, the gaps between the cylinders being closed by milliammeters placed in them. The pressure of the hydrogen in the tube was 1.11 mm. V is the voltage across the whole tube, v the potential relative to the anode at which the cylinders are maintained, I the main current, i_1 the current between D and E, i_2 that between E and F, and i_3 the current from F to the cathode through the auxiliary battery. The data in row I apply to the case where v is the floating potential assumed of itself by the cylinders and as well to that where v is maintained at the same potential by a battery. Both i_1 and i_2 are here wall currents resulting from ion diffusion. In row II, the potential v of the cylinders was 409 volts above that of the cathode, which is 73 volts more than that assumed by it while insulated when the same current was flowing. The total voltage across the tube was however considerably smaller. Since 3.15 m.a. flowed through the battery to the cathode only 0.85 m.a. went by the gaseous path, and the glow on the cathode diminished in intensity correspondingly.

The currents i_1 and i_2 are, in considerable part, portions of the main current flowing to the gauzes that served here as the real cathode for 3.15 m.a. of the current. Diffusion of ions must also have contributed to the wall currents. In row III, the total voltage V was larger than in the previous cases but the potential v was really 13 volts smaller relative to the cathode than in row I. A current of 2 m.a. now flowed from the cathode to the cylinders through the battery and hence the current from the cylinders to the cathode through the gas was increased to 6 m.a., and the glow at the cathode was therefore brighter than before. i_1 and i_2 are not greatly different from the wall currents given in row I.

DISCHARGES THROUGH METAL TUBES HAVING ENDS CLOSED WITH METAL GAUZES.

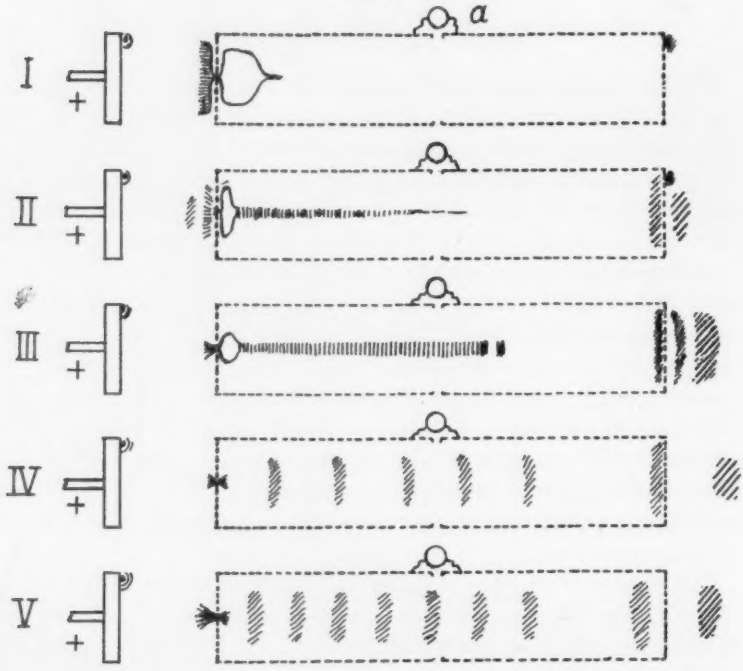
Rather surprising results were obtained when the ends of a gauze cylinder 11 cm. long, which was inserted in the discharge tube, were completely covered by discs made of wire gauze of the same small mesh as that used for the rest of the cylinder. These discs were silver soldered to the ends of the cylinder so that no larger openings were present than the mesh openings in the gauze. Even under these conditions a discharge could be made to pass through the gas within the wholly enclosed cylinder, and often the path of this discharge was striated. The discharge usually all entered the enclosed space through but one of the openings whose area was only about 0.02 sq. mm. As this opening might chance to be one near the periphery, in some of the experiments the central opening was enlarged to a diameter of 1 mm. to make the discharge enter on the axis of the tube for the sake of symmetry.

An example of one of these discharges is shown in Fig. 2*e*. The number of striæ present in the positive column within the closed cylinder shows that there is a very considerable fall of potential between the ends of this column. The widely spaced striæ at the right were pinkish in color while those at the left were blue, a combination not infrequently noted in discharges through hydrogen. Sometimes a few of the striæ within the cylinder were tilted. Such tilting in glass discharge tubes has usually been ascribed to an unsymmetrical distribu-

tion of charges on the adjacent walls of the tube. Here, and in metal tubes with open ends, the tilting when present seems rather to arise from a lack of symmetry in the distribution of charges outside of the cylinder at or near the end that faces the cathode. Figure *2f* shows an example of an unusual and rather unstable condition where two solitary striæ appeared for a short time near the center of the closed gauze cylinder.

The process by which the discharge manages to penetrate the gauze and make its way through the center of the cylinder is illustrated in Fig. 5 by sketches made of discharges seen at

FIG. 5.



different pressures. The closed gauze cylinder was here cut transversely into two equal parts in order that the current flowing through the walls of the cylinder could be measured by the milliammeter "*a*," inserted between these parts. The current-voltage relations which prevailed in each case are

given in Table 3 in the same order as the drawings, p being the gas pressure in millimeters, V the total voltage across the tube, v the potential difference between the gauze cylinder and the anode, I the main current, and i the current between the two portions of the cylinder.

With small currents, especially at the higher pressures, the cylinder simply divides the discharge into two parts, the current going from the anode to the outside of the interposed cylinder and leaving at the other end for the cathode. As the current is increased the negative glow on the end of the cylinder which faces the anode spreads over more and more of the surface until finally it suddenly penetrates one of the mesh openings in the gauze and begins to spread over the inner surface of this gauze as well. The current thus flows from the glow to the end face of the cylinder at both its outside and its inside surfaces. Since an increase of current density of flow from a gas to a metal above the so-called normal value would involve an increase in the cathode fall of potential, any increase in the total current is here preferably accommodated by an increase in the area of flow, even though in this case it involves the spreading of the negative glow through a small opening in the gauze onto the inner surface. The glow is very bright where it passes through the gauze.

I in Fig. 5 shows a somewhat advanced stage of what has been described above. The luminosity of the bulb-shaped glow inside of the cylinder is mostly confined to the surface portions and this glow is in every way like the glow seen in Fig. *2b* and possesses the same pointed end. As is seen from Table 3, none of the current here passes through the gas down the length of the cylinder.

TABLE 3.

	p	V	v	I	i
I.....	2.73	1026	502	10.0	10.0
II.....	1.74	1050	590	3.25	3.3
III.....	1.74	926	377	10.0	3.5
IV.....	0.86	1000	289	10.0	2.12
V.....	0.335	1620	286	4.5	1.06

In II the pointed end of the glow inside of the cylinder has enlarged into a long narrow streak of light in which some

striations are visible. This stage is somewhat analogous to that shown in Fig. *2c* where the cylinder has open ends. The general appearance indicates that a small fraction of the current may now be passing down the whole length of the cylinder although the current readings do not show this, possibly because the current through the gap between the two parts of the cylinder involves diffusion currents as well. An increase in the main current from 3.25 m.a. to 10 m.a., with the gas pressure unaltered, produced the marked changes shown in III. The negative glow has disappeared from the left end of the cylinder, a more definite positive column has appeared, and the larger portion of the current now flows down the center of the tube and no longer has to overcome the cathode fall of potential at the surface of the cylinder. In consequence the total voltage across the discharge tube has decreased even though the total current has increased. The bulbous form of the left end of the positive column indicates that some of the main current still flows to the walls of the cylinder at this place, and this together with the diffusion currents present accounts for the current flowing across the gap between the two portions of the cylinder. The changes noted had already taken place when the current was but 5 m.a., the voltage across the tube being then 845 volts, that of the cylinder 379 volts, and the current across the gap 2.7 m.a.

IV and V show discharges at lower pressures, where clear cut, widely separated striæ are present in the cylinder. The current still enters the cylinder through only one of the openings in the gauze, and now all, or practically all, of it passes down the center of the cylinder and appears to leave it through a considerable area of the right hand end. It is estimated from the number of striæ which appeared at times inside the closed cylinder that the total fall of potential through the gas inside of it must under such conditions have been at least as much as 150 volts.

Hufford [11] performed an experiment in which two metallically-joined discs were placed 4.8 cm. apart in a discharge tube of 3 cm. diameter, and while one of the discs, which was perforated with a small hole, was used as the cathode for the

[11] M. E. Hufford, *Phil. Mag.*, **50**, 1197 (1925).

discharge in the tube, a probe in the space between the two discs was found to assume a potential of 400 volts above that of the discs, when the total voltage across the discharge tube was but 550 volts.

Figure 3*f* shows the appearance of a discharge through a tube in which two discs, each 3 mm. thick and having a hole of 2 mm. diameter through its center, were placed between the anode and the cathode in the region of the positive column. The discs were joined together by a narrow metal strip and were insulated. It is to be noted that the striæ in the space between the discs have the same large diameter as those outside of this space whereas the diameter would have been smaller had the space been completely enclosed in metal walls. The glass walls here prevent wall currents and permit the existence of a considerable difference of potential along their length.

GENERAL REMARKS.

From what has been said it seems apparent that the differences Gehrcke [7] observed in the appearance of the striæ in a positive column, when passing through a glass tube covered on the inside with a transparent coating of silver and when coated with phosphoric acid, is probably due to the fact that in the first case the resistance of the coating was so high that during an experiment a considerable difference of potential could be maintained between its ends by the discharge, whereas with the better conducting phosphoric acid this was not possible.

Gehrcke states that possibly the positions of the striæ in a glass discharge tube become stabilized by the formation of charges on the surface of the glass whose magnitude changes periodically along the length of the tube. Since, however, equally stable striæ appear in portions of tubes having conducting walls the condition postulated is not a necessary one.

The large differences of potential that were found between some parts of the walls of a discharge tube when made of metal and the positive column within, naturally do not exist in tubes made of non-conducting material. Salinger,[4] who made measurements of the radial distribution of potential

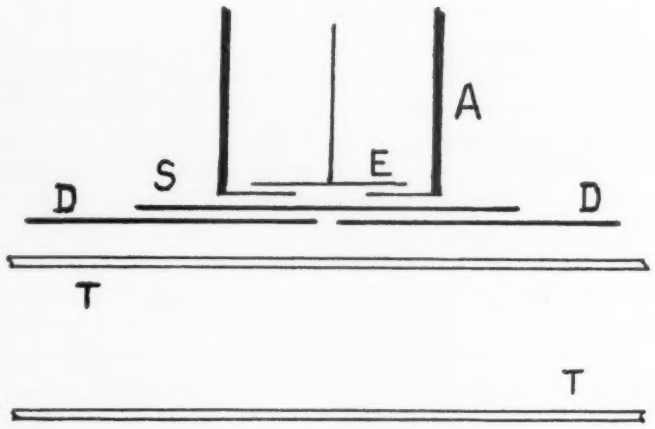
within a glass tube of 4.5 cm. diameter through which a discharge was passing, showed that in the region of the positive column the maximum potential difference between the wall and axis of the tube was in general less than 10 volts and at times less than half this value. The energies obtained by electrons from the axial field in the positive column are quite sufficient to enable them to diffuse against a barrier of this magnitude, so that in such tubes both electrons and positive ions doubtless migrate to the walls. In the steady state, any surface element of the wall must receive the two kinds of charge at equal rates and this is automatically brought about by the formation of a space charge that gives rise to a radial field by which the positive ions are assisted and the electrons retarded in their radial motion by just the proper amounts to ensure equality of flow. This process does not necessitate and neither does it abnegate the formation of surface charges on the walls of a glass tube. Where the discharges here studied passed through long sections of metal tubing, evidently no large surface charges were present on the walls. This must be equally true of the well-known low pressure arc discharges within metal walls. The axial as well as the radial fields in these cases are determined mainly by space charges within the tubes. It has just been shown that in glass tubes, too, surface charges are not indispensable for the maintenance of the radial fields in discharges within them. Other conditions which must be satisfied may well make their presence necessary.

DISTRIBUTION OF SPACE AND SURFACE CHARGES ON THE WALLS OF A GLASS DISCHARGE TUBE.

It seemed desirable to make at least a qualitative determination of the distribution of both the space and wall charges in a glass discharge tube. The method adopted for the purpose consists in letting different limited portions of the discharge tube to act inductively in succession, through a slot in a metal screen, upon a plate connected to a quadrant electrometer. Taken with the discharge current going, the electrometer deflections are a measure of the combined surface and space charges in the region exposed. After the discharge current is cut off, only surface charges are operative.

The question naturally arises whether the surface charges thus measured have the same value as they had when the current was passing through the tube. It is possible, and indeed probable, that, while much of the space charge was drawn to the electrodes after the current was broken and before the electrodes were both grounded, some of it may, nevertheless, have lodged on the tube walls. As no way was apparent for determining the importance of this factor, in what follows it will be arbitrarily assumed that the electrometer deflection obtained after the current was interrupted represents, at least approximately, the effect of the desired

FIG. 6.



surface charge, and that the difference between the deflections with the current on and off represents the effect of the space charge that was present in the exposed portion of the tube when the current was passing through it. A several-fold increase in the current was found to have but a minor influence on the results obtained.

Figure 6 shows in plan the essential parts of the apparatus used. The discharge tube *TT* had an external diameter of 2.24 cm., and the distance between its plane aluminum cathode and its spherical anode of 5 mm. diameter was 37 cm. It was operated by a storage battery. A support permitted the tube to be moved in the direction of its length in front

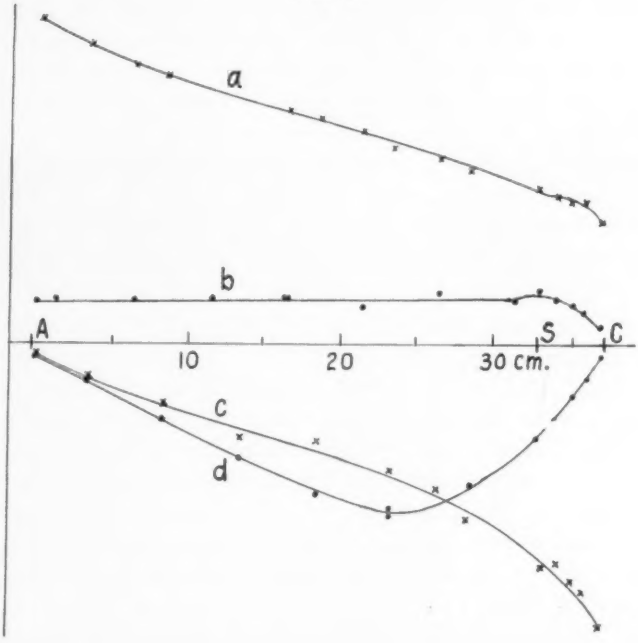
of a vertical slot, 2.5 mm. wide, in the metal diaphragm *DD*, which in turn was placed 4 mm. from the disk *E* that was connected to the quadrant electrometer. The wall of the discharge tube was 4.5 mm. from *DD*. *E* was surrounded by an earthed cylinder *A* whose end was closed by a disk having in it a vertical slot 1 cm. wide. In the position shown, the earthed shutter *S* effectively shielded *E* from all inductive action by any charges on *TT*.

The following procedure in taking readings was used. The current was started in the tube with *S* closed. The electrometer quadrants being insulated, *S* was moved aside, and the electrometer reading, due to both the volume and surface charges on the exposed portion of the tube, taken. *S* was closed again, the current was interrupted, both electrodes of the tube were grounded, *S* was opened, and the deflection due to surface charges alone was read. The walls of the tube having been cleaned with special care during manufacture, the surface charges leaked off so slowly that no correction had to be made for such leakage during the time taken for a reading of a deflection. The area of the tube wall from which any inductive action on *E* can take place is more limited on the side next to the slot in *DD* than it is on the more remote side but since the effective configuration remains unchanged when the tube is moved in the direction of its length the successive electrometer deflections are proportional to the charges on the corresponding equal areas of the walls. The question arose however whether the difference between the deflections with the current on and off, which is being taken to represent the effect of space charges alone, may be used correctly with the deflection due to the surface charges alone for finding the relative magnitudes of the space and surface charges involved. A graphical integration study based on the geometry of the case and the relative inductive actions of a charged metal strip when placed at different distances from the slot in *DD* led to the conclusion that such a comparison of deflections may be made without serious error. This conclusion was confirmed by the close similarity found between the results obtained with the arrangement described above and those obtained when the discharge tube was placed coaxially in a long metal cylinder of 7.6 cm.

diameter, in which case the distances of the different portions of a section of the tube from E were all greater and hence more nearly equal.

A typical set of results is shown in Fig. 7. The gas used was air at a pressure such that, with a discharge current of 1 m.a. which was used throughout, the width of the Crookes dark space was 2.5 mm. The voltage across the tube varied between 1210 and 1170 volts during the measurements. The

FIG. 7.



distance between the cathode (marked by C) and the head of the first stria (marked by S) in the positive column was 4.2 cm. A gives the position of the anode.

One set of readings was taken with the cathode of the tube grounded, and another set with the anode grounded. Curves a and b give the deflections obtained with the current on and off respectively when the cathode was grounded, and c and d are the corresponding curves when the anode was

grounded. There is a marked parallelism between curves *a* and *c*, both representing charge distributions responsible for the axial field in the tube which must necessarily be the same at corresponding points in the two cases. Curve *a* shows a positive charge throughout which diminishes gradually in passing from the anode toward the cathode. Owing to the large fall of potential at the cathode, the positive charge near this electrode still has a considerable magnitude even though the electrode is grounded. The outermost readings at both ends were taken with the inner surface of the electrode in line with the outside edge of the slot in *DD*. The charges indicated by curve *c* are all negative, beginning with a low value near the grounded anode and increasing steadily throughout the length of the tube. While the slopes of the curves *a* and *c* are nearly alike the positive charges on *a* are everywhere larger than corresponding negative charges on *c* when the two distances are measured from opposite ends of the tube. This arises from the lack of symmetry in the tube due to the large fall of potential at the cathode. There is some evidence that on a curve like *a* the differences in space charge between a stria and an adjacent dark space, though small, can be detected by this method of measurement.

Turning to curve *b* which represents the surface charges measured after the discharge current was interrupted while the cathode of the tube was grounded, it is seen that these charges are everywhere positive in sign and that their value remains quite constant over the whole length of the positive column, and hence, subject to the assumption made initially, surface charges here made no contribution either to the axial or the radial fields.

The distribution is radically different in curve *d* which represents the surface charges when the anode was connected to earth. The charge here is everywhere negative, being small near both electrodes and having a maximum value on the cathode side of the middle of the tube. Taking the differences between the ordinates of the curves *c* and *d* to represent the space charge, it is seen that this charge has the largest negative value near the cathode, that it diminishes rapidly with distance, that it reverses in sign about 10 cm. from the cathode and from there up to the anode remains

positive. The large difference between the curves *b* and *d* is probably connected with differences in the positive and negative charge carriers.

It should be emphasized that the measurements were all made within a narrow range of pressures within which alone sufficiently steady conditions could be maintained in air. At a lower pressure than was used above where the Faraday dark space was about 10 cm. long there was a distinct hump in curve *a* in this region; and there is some evidence that the distribution shown by curve *d* is especially sensitive to changes in conditions. Some idea of the magnitudes of the charges which were induced on *E* may be had from the fact that when a brass tube of the same diameter as the discharge tube was put in place of the latter and charged to 314 volts the potential indicated by the electrometer, of capacity about 40 cm., was 0.023 volt, which is about a fifth of the maximum on curve *a*.

I wish to acknowledge here the valuable help received at different times from Dr. C. D. Bock, Dr. R. L. Anthony, and Mr. L. Hurwitz in the performance of the experiments.

"The Paratex" Diesel-Engined Tanker.—B. J. VON BONGART. (*Diesel Progress*, May, 1938.) The "Paratex" is a tank ship of modern construction placed into service by the Gulf Oil Corporation. The construction is unique in many respects and it should arouse unusual interest. The vessel is intended for coastwise, inland waterway, and Great Lakes service and is equipped with no less than seven diesel engines, two for propulsion and five for cargo pumping services and for the generation of electric current. The propulsion engines are the Alco-Sulzer type TM, reversible, 2 cycle, 4 cylinder, of 14 inch bore and 23 ½ inch stroke delivering 720 bhp. at 277 r.p.m. These drive the loaded tanker at a speed of 10 knots on a draft of 14 feet. The propeller is direct driven, the control of the engines accomplished by but two levers. One regulates the fuel injection and the other controls the starting, stopping, and reversing. The electric services supplied from other engines provide a great variety of service including heating of pilot houses, water heater, and an electro-hydraulic stearing gear. The hull of the vessel is of all steel construction and electrically welded throughout. Bulkheads divide each of the four main cargo oil tanks into triple tanks. The length overall is 257 feet, 3 inches with a beam of 43 feet. The cargo capacity is 20,000 barrels. Modern vessels no longer feature the ancient and venerable fo'c'sle and the ancient "gloryhole" (crews' quarters); on the "Paratex," officer and crew accommodations are in a neat steel house aft. There are two pilot houses, one well forward and recessed in the forehold so that it can be lowered when the vessel must pass under a low bridge. The other pilot house is located about 87 feet from the bow. This is added because of the fact that during the winter months she will be used in coastwise service which naturally requires operation at sea when the forward pilot house is retracted into the hold. It is built in sections so that when the vessel is used in canal service it may be taken apart and stowed on deck. Navigation facilities include a Cory electric telegraph, Typhon air whistle, radio direction finder etc.

R. H. O.

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Assistant Keeper.

The formation of a museum of science and industry in London was first proposed by the Prince Consort after the Great Exhibition of 1851. Various technical collections and educational apparatus which had been shown in that Exhibition were therefore retained to form the nucleus of such a museum. To house these and other scientific exhibits, a temporary iron hall was erected, which H.M. Queen Victoria opened to the public in June 1857. Seven years later a collection of ship models was added, and about the same time the exhibition was transferred to temporary premises on the present site. The collections of scientific instruments and apparatus were formed soon afterwards, and in 1883 the contents of the old Patent Museum were added. At that time the science and art collections were known as the South Kensington Museum, but in 1909 the art collections were separately housed in the Victoria and Albert Museum, and from that date the machinery, ship models and other scientific collections have formed the Science Museum.

Some of the old halls built for the Exhibition of 1862 are still in use, but will ultimately be replaced with a modern structure, to comprise about 500,000 sq. feet of floor area, basements included. Of its three main blocks, the Eastern Block alone has been completed, and this was opened in 1928 by H.M. King George V. The main entrance is in Exhibition Road, and open free to the public from 10 A.M. until 6 P.M. Monday to Wednesday, until 8 P.M. Thursday to Saturday, and on Sundays from 2.30 to 6 P.M. From the marble floor of the entrance hall, an extensive view over the interior of the Eastern Block is obtained; this is indeed a technical museum on the heroic scale (Fig. 1). On the left is the staircase to the upper floors, in the well of which is suspended

a Foucault pendulum of 80 feet, to demonstrate the rotation of the earth. Here is also the entrance to the Children's Gallery, which will be described later. On the opposite side of the entrance is the main bookstall, where handbooks and

FIG. 1.

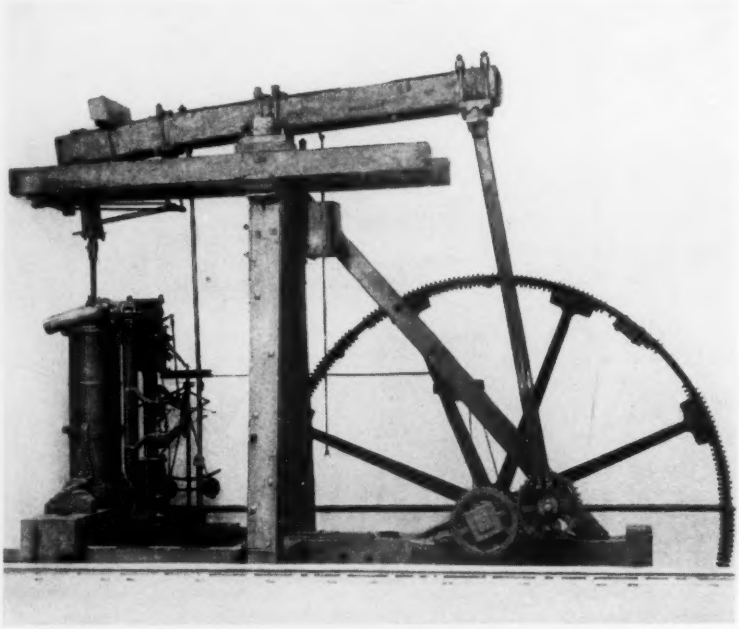
Interior of the East Hall.

other publications, and all information about the museum can be obtained. Public lectures and demonstrations are announced on the notice boards. Behind the bookstall is a hall reserved for special exhibitions, such as that of Television, where items of topical interest, the results of current scientific

research, or recent important acquisitions are shown as occasion demands.

Ahead of the main entrance, marble steps lead down into the East Hall, where some of the mammoth prime-movers of olden times have been erected, and can be shown in motion. The work of Newcomen, who first harnessed the power of steam in 1712, is represented with operable models of his

FIG. 2.



Watt's sun-and-planet mechanism (1788).

steam-driven pumps which were used to drain coal mines. The up-and-down movement of the piston was later converted into rotary motion, and used to drive mills and workshops; the famous sun-and-planet mechanism of Watt, which rendered this possible, is shown in operation (Fig. 2). The work of Trevithick and other pioneers is also well represented. The ideal of rotary motion direct from steam, foreshadowed in the æolipile of Hero, was achieved centuries later in the turbine. The first steam turbine of Sir Charles Parsons can be com-

pared with the model of a modern 50,000 kw. power unit. Sectioned examples and models of de Laval, Curtis and Rateau turbines show their principles of operation. On the left are models of wind-mills, and primitive water-wheels constructed of wood and iron. Modern water pressure turbines, such as the Francis, and Pelton impulse wheels are

FIG. 3.

The "Rocket" locomotive (1829).

shown in models. The development of steam boilers, down to the modern Babcock and Wilcox water-tube boiler, is also well represented. Mechanical stokers, pulverised coal and oil-fuel burners are shown in the wall-cases.

In the locomotive department, on the opposite side of the East Hall, is one of the most treasured possessions of the museum, the "Rocket" locomotive of Stephenson (Fig. 3).

Beside this old veteran is a sectioned replica which can be shown in motion. Recent steam, electric and internal combustion locomotives are illustrated with scale models. The action of the Walschaërts and other modern valve motions are demonstrated with models which the visitors can operate for themselves. Other railroad material in this hall includes models of the earliest vehicles, compared with modern saloon cars and sleepers, and trucks for the transport of merchandise.

FIG. 4.

Workshop of James Watt (1819).

Behind these collections, is the lecture hall with seats for close on 200 persons, and facilities for demonstrations and motion pictures. Free lectures for the public are held here daily. At the side of the lecture hall is the main lift, which provides access to all floors. In a corner is the workshop of James Watt (Fig. 4), which has been removed from Staffordshire with all its contents, and reconstructed in the museum. From here a corridor leads into the hall devoted to scientific measurement, which is presented under the three heads of

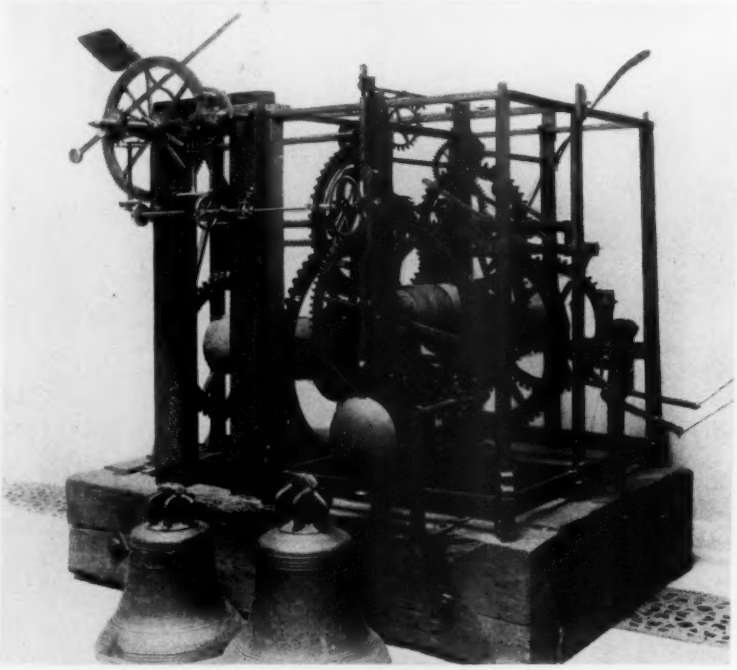
linear, mass and volumetric determinations. The instruments and standards of reference which have been used over a period of some five thousand years are shown, from primitive pivot scales to modern chemical and bullion balances, and optical instruments which indicate to the millionth part of an inch.

The aeronautical department is most comprehensive in scope; and at the outset are exhibited some beautiful specimens of birds as natural aviators. Now follows the whole drama of human ascent, first in balloons and airships, and later in heavier-than-air craft. The detail development in all these forms of aircraft is shown in a series of more than a hundred scale models; in addition, however, numerous authentic machines of historical interest are exhibited, and in this respect the collection is unique. From one of the earliest airships, that of Henri Giffard, development up to the modern "Graf Zeppelin" is traced. There is a replica of the Blériot cross-Channel aeroplane (now preserved in the *Conservatoire National des Arts et Métiers* in Paris), and the first non-stop trans-Atlantic plane. The development of the aero-motor is illustrated with about 80 examples, from the earliest steam-driven machine of Maxim; some of them are sectioned and shown in movement, so that the action of their internal mechanism can be studied. Gliders on exhibition include the experimental machines of Lilienthal and Weiss. There is a comprehensive collection of aeronautical instruments shown in wall-cases, and other exhibits to illustrate the components and structure of aircraft.

The historical collection of railroad construction shows the development of track material from the earliest times, from the wood, cast-iron and steel rail periods; ties of stone, wood and pressed steel are also exhibited. Third rail and overhead wires for electrical operation show the most modern development. In another corner of this room, is the clock from Wells Cathedral, one of the earliest in existence, which was made in the fourteenth century (Fig. 5). This old clock is still in operation, and strikes the quarter-hours. One of the most important exhibits, however, is the after-part (about 50 ft.) of the S.S. "Turbinia." This was the first turbine-driven vessel, of 2000 horse-power, in which Sir Charles

Parsons conducted his pioneer experiments. Other exhibits show the development of marine steam turbines, down to those of the R.M.S. "Queen Mary" with about 200,000 horse-power. The next room is devoted to fire protection and the mechanical transmission of power, with models of belt, rope and chain drives, various forms of toothed wheels and clutches.

FIG. 5.

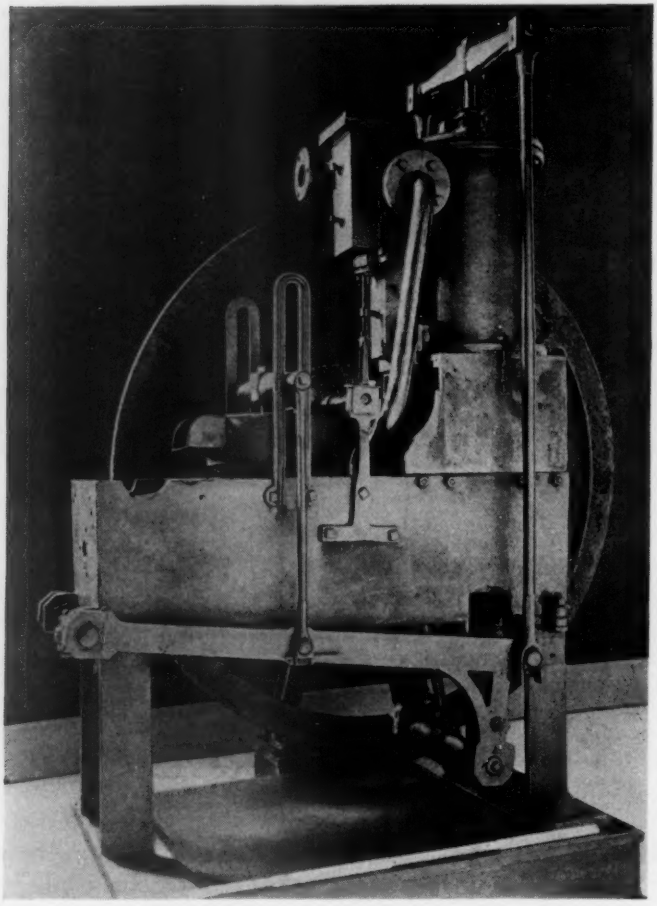


Clock of Wells Cathedral (c. 1325).

Models of harbors and docks trace the development which has taken place, from about 1821 to recent times, while there is also an attractive collection of anchors. Marine steam propulsion is shown with models in motion, some of them sectioned to show the internal construction; these are perhaps the finest collection of their kind in existence. Two historical machines are exhibited; the one which Patrick Miller used in his first experimental steamboat of 1788, and

the other from the P.S. "Comet" of 1812, the first steam vessel used for public service in Europe (Fig. 6). The transition from paddle-wheel to screw propeller is illustrated

FIG. 6.



Machinery of the P.S. "Comet" (1812).

with models in the wall-cases. Hand and steam tillers include those of Harfield and Brown; these models are provided with controls for the visitor to operate. The evolution of the marine steam boiler can be seen in models of the earliest flue

and fire-tube boilers, modern Scotch boilers with superheaters, the Yarrow water-tube boiler, and an oil fuel installation.

Road construction is contrasted with sectioned models of the old Roman roads in Great Britain and the modern arterial roads of reinforced concrete. Specimens of road materials, such as stone, wood and asphalt, reinforced concrete, rubber and iron, are exhibited, as well as models of road rollers and other implements. The development of wheels for road vehicles, from the primitive roller, includes also a replica of an ancient chariot wheel. Historical horse-drawn vehicles from the Royal Mews are exhibited, while numerous models show the different forms of horse-drawn carts, Hansom-cabs and London omnibuses. Authentic exhibits in their historical order trace the development of the modern bicycle from the first wooden hobby-horse of 1818, the pedal-driven machines of Macmillan, and the notorious old "boneshakers" before the introduction of india-rubber tires. The details include an example of the Dunlop pneumatic tire of 1888, and sectioned parts and components to show how modern machines are constructed.

The automobile section includes models of the steam road vehicles of Murdock and Trevithick, and the White steam car. The first motor cab, the Bersey electric vehicle, which plied for hire on the London streets should be noticed. Some of the earliest petrol-driven automobiles include a Benz of 1888, and later examples of Panhard, Cannstatt-Daimler and Lanchester. Chassis of recent cars include the Ford, Vauxhall and Humber (all of which can be seen in motion), also the Morris and the Austin Seven. Modern automobile details and accessories form a comprehensive collection, with numerous sectioned and operable exhibits. The half-section of an all-steel motor-car shows how the latest method of welded construction is carried out.

Above the main entrance, on the first floor, are the models of sail ships. Here can be seen the "Santa Maria" in which Christopher Columbus sailed to discover America, and the beautiful model of an Elizabethan Galleon (Fig. 7), made in the museum workshops. The famous "Cutty Sark" shows the last development of sail in the clipper ships, before the advance of steam put an end to their further construction.

Other models trace naval development, from the earliest wooden warships with paddle-wheels or screw propellers to aid their spread of sail, down to modern armour-plated battleships. Here can be seen H.M.S. "Monarch" with other models of cruisers, torpedo-boats and submarines. The next section deals with the work in collieries, how the shafts are sunk, supported with timber props and ventilated, and

FIG. 7.

Model of Elizabethan Galleon (c. 1600).

how the coal is hoisted to the surface. Metalliferous mines are also represented, because of their importance in the British colonies and dominions. The treatment of ores taken from the mines, in order to extract the metal and prepare it for industrial use, is shown with models of blast furnaces and modern electrical furnaces. There is the old muffle furnace which Sir Isaac Newton is supposed to have used when Master of the Mint, also specimens of the alloy-steels which

Faraday used for his pioneer research work. The electro-deposition of metals is shown, while their inner structure can be studied from atomic models and specimens under the microscope. Some of the 3700 specimens which form the famous Percy collection are exhibited.

The textile department shows the preparation of raw materials, such as cotton and flax, wool and silk, for manufacture into yarn. How the spun thread is woven into cloth is demonstrated with models and actual examples of the old hand loom and a modern power loom, all of which can be seen in operation. The evolution of simple hand tools, such as the axe and chisel, hammer and drill, from the stone implements of prehistoric times, is shown with numerous exhibits. Machine tools include a model of the first steam hammer, and some historical machines, such as the Maudslay lathe and one of the earliest metal planers. The evolution of the lathe can be followed, from the primitive Eastern bow lathe to the complicated capstan machines of modern practice.

Electrical power, one of the most important factors in our modern civilization, is traced back to the fundamental experiment of Faraday, which visitors can repeat for themselves. Some of the earliest alternators and direct-current machines are exhibited, with Gaulard and Ferranti transformers, switches and circuit-breakers, and an instructive collection of electrical instruments. Transmission includes the first Ferranti paper-insulated cable; accumulators are also shown. Under electrical communication are to be seen the telephones of Bell and Edison, and specimens of submarine cable. The complete sectioned model of an automatic telephone station is shown in operation, while the apparatus with which Baird made his first experiments in television is also exhibited. The development of radio is traced back to the pioneer work of Hertz, replicas of whose apparatus are shown; the contributions of Marconi and others follow, with numerous examples of detectors and broadcast receivers, microphones and loud-speakers. The museum demonstration receiver and loud-speaker has a 27-foot exponential horn (with aperture 7 ft. square) to reproduce the local broadcasts.

Farm implements show how the soil is tilled, the seed sown, and the harvest reaped and threshed. The evolution

from the primitive hand plow to the modern power-driven implement is traced with models. Other exhibits include a butter churn of the seventeen-hundreds, and the first Alfa-Laval cream separator. Glass production now follows, with models of furnaces and samples of the materials used. The manufacture of bottles can be seen, and the mass-production of bulbs for electric lamps and radio valves. Models of kilns, one of them from the Romano-British era, show the traditional manufacture of bricks and of eathenware pots and drain pipes. The development of artificial illumination is traced, from the rush and tallow dip candle, and the various forms of oil lamp, to the incandescent mantle and the modern electric lamp. One notable exhibit is the first successful carbon filament electric lamp, which Joseph Swan made in 1878. Now follow collections to show the development of quill and steel pens; also the art of the printer, from the wooden hand press of Jacobean times down to modern methods and machines. The manufacture of paper, and the preparation of wood pulp, can be seen in models, one of which shows the latest modern practice.

The second floor of the museum contains the historical model collection of merchant steamers and motorships. Here can be seen the paddle steamers "Sirius" and "Great Western" which were the first ever to cross the Atlantic under continuous steam power. Other notable models include the "Great Britain" which was the first screw steamer to cross the Atlantic, and the famous "Great Eastern." Further down the hall, a fine model of the "Empress of Britain" shows modern practice, while the French liner "Normandie" and the R.M.S. "Queen Mary" are also represented. Motorships include the oil-tanker "Vulcanus" which was the first Diesel ship for ocean service, also a handsome model of the M.S. "Carnarvon Castle." In the mathematical section can be seen various mechanical devices used in calculation, from the primitive abacus to the modern slide-rule and machines, such as the Hollerith, for statistical work. Other branches of pure science include acoustical phenomena, with instruments for sound reproduction, and the measurement of time. Here are some ancient water-clocks and sundials, and an extensive collection of watches and chronometers. Various forms of

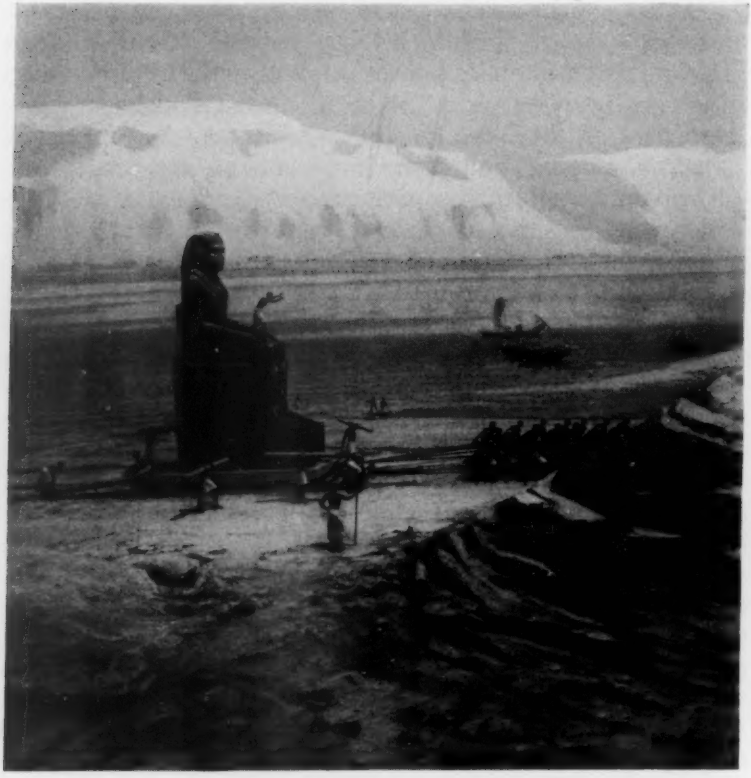
escapement are shown in models, while a Shortt free pendulum clock mounted on the wall controls the main public dials in the museum.

The collection of pumps, which starts with the Archimedean screw, comprises the most primitive hand and animal-driven forms, and modern pumps and compressors for power transmission, blowers for ventilation, and vacuum pumps as used to exhaust electric lamp bulbs and radio valves. Notable exhibits are the Bramah press, a piston pump which Braithwaite made in 1817, and the first turbine pump of 1887. Municipal water supplies are shown, with particular reference to the London reservoir at Staines. Other models show the Aswan dam on the Nile; specimens of Roman and mediæval lead pipes, wooden and stone water mains, for comparison with modern steel mains; domestic water-meters, and the development of the household water-tap. Structures in timber, steel and reinforced concrete are shown in models, which include the famous oak hammer-beam roof of Westminster Hall built for Richard II. There are also models of pile-drivers which can be seen in operation. Municipal sanitation, as carried out in the more important towns of Great Britain, completes the collections in this department.

On the third floor are the historical collections of fisher boats and other small craft, which include models of wherries, smacks and trawlers from various parts of the British Isles; the small craft of other countries are also well represented, and include some fine models of Chinese Junks. The optical department contains one of the finest collections of microscopes in the world. The development of the terrestrial telescope is shown, and a number of ophthalmic instruments. Cameras and sensitised plates form another historical collection, which dates back to the first photo-impressions of 1827, and includes some of the earliest prints extant. Motion picture cameras and films are shown, with some of the mechanical devices which preceded the cinema, and in which an illusion of motion was produced. Astronomical models and instruments include replicas of Galileo telescopes, models of observatories, and historical instruments of Sir William Herschel and others. The chemical department shows the work of Alchemists in mediæval times, and contains a fine

collection of chemical elements shown under their periodic classification. Other exhibits deal with the preparation of ozone, the importance of vitamins, and the properties of radio-active substances. Models and specimens show the commercial mass-production of chemicals, such as mineral acids and alkalis, coal-tar distillates and explosives.

FIG. 8.



Diorama of Ancient Transportation.

One of the most popular innovations at the museum has been the provision of a Children's Gallery in the basement, to which a short staircase leads down from the entrance hall. Some of the fundamentals of technical science are here treated in a simpler manner than is possible in the main collections.

First of all we find a practical demonstration of the rainbow, while near at hand are other exhibits to show various methods of time measurement and applications of the photo-electric cell. The development of land, marine and air transportation, from prehistoric to modern times, is shown in a series of eleven dioramas (Fig. 8). Others deal with the evolution of domestic interior illumination; while two kitchens, one modern and the other a hundred years old, provide an instructive

FIG. 9.

Science Museum Library.

contrast in detail. The elements of mechanics are demonstrated with simple tackle, such as a windlass, which the children can operate for themselves. Methods of communication can also be studied, from the primitive beacon to the modern automatic telephone station. At the end is a small cinema, where educational films are shown.

Attached to the museum, is a national reference library of more than 270,000 volumes devoted to pure and applied

science, known as the Science Museum Library (Fig. 9), which the writer has described elsewhere.[1] All the books and periodicals are card-indexed for reference in accordance with the decimal classification. The museum workshops (not open to the public) are located in the basement, and include wood and metal shops with 32 skilled artisans for the construction and repair of models and other exhibits. The scientific staff of the museum and library, under the Director, Colonel E. E. B. Mackintosh D.S.O., comprises 30 keepers and assistants. The technical, clerical and operative personnel number close on 280, all warders, labourers and cleaners included. Records of attendance show that about 1,280,000 visitors per annum come to press buttons and turn handles, hear lectures and see demonstrations, and so learn the fundamentals of technical science. The practical and material trend of modern life has made this one of the most popular of our national museums.

[1] Spratt (H. Philip), "Libraries for Scientific Research in Europe and America." 227 pp. with frontis. Grafton and Co., London, 1936.

CRITICAL REMARKS ON THE INTERPRETATION OF QUANTUM THEORY.

BY

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1. Reality and interpretation.
   Dualism of interpretation. The corpuscular statistical interpretation of the wave density and the wave interpretation of discontinuities of energie represent untenable absolute standpoints as against the relativity of quantum theory.
2. Kinematics of diffraction.
   Equivalence of Huyghens' resonance and corpuscular transmissions of momentum. Length as a wave attribute, momentum as a corpuscular attribute. The compromises of the absolutists are based on over-interpretations. Modified meaning of the uncertainty relation. Classical versus wave and corpuscular view.
3. Quantum dynamics.
   Expansion of the range in space, contraction of the range of momentum. Corpuscular process relating wave data, wave process relating corpuscular data. The prototype of quantum dynamics. Prestabilized harmony between waves and particles.
4. Fluctuations.
   Particles and waves appear as limit cases of fluctuations. Classical and quantum theoretical undeterminacy. The emission of α-particles and α-beats.

§ 1. REALITY AND INTERPRETATION.

When we wish to obtain information about a physical object, for instance when we ask for the position, volume, or energy, of a quantity of matter, we cannot draw conclusions from what we see before we have postulated a certain manner of *interpreting* the optical signals, that is, before we have

presupposed a certain theory as to the constitution of the light received and its interaction with matter. Of course we are not allowed to invent such a theory at will. Instead we have to build up the theory of interpretation in such a way as to bring to a common denominator as complete a set of experiences as possible. This purpose is achieved to a certain extent by the *corpuscular theory of light*, established by Newton, revived by Einstein, according to which light is supposed to consist of photons that are capable of interacting mechanically with matter, the latter being supposed to consist of particles, too. As this hypothesis accounts for a great variety of phenomena (reflection, refraction, and also the so-called interference phenomena as diffraction and polarization, refer to § 2), the corpuscular hypothesis obtains more and more the character of a reality: light and matter consist "in reality" of particles reacting mechanically.

Now it happens that the same fundamental experiences may just as well be understood from the wave point of view according to the *undulatory theory* established by Huyghens, extended by Fresnel and Maxwell, and transferred to matter by de Broglie: light and matter consist "in reality" of vibrations that are subject to the principle of superposition.

In addition to the previously mentioned stationary phenomena there is a wide range of phenomena to be classed as dynamical processes, where we succeed in getting a rational description only by using a peculiar method of changing over from the corpuscular to the wave theory and vice versa (§ 3). The problems of dynamical stability (Eigenwert problems) and fluctuations (§ 4) belong to this class. We prefer here to speak first of *what* we see (Kinematics) and later on of *why* we see it (Dynamics).

We might be disappointed, in view of our desire to have a uniform picture of the physical world, to be confronted with two equally justifiable images. We must not forget however that these images are to a certain extent results of our subjective interpretation, and that *absolute reality ends where there are several equivalent physical realities.* In the theory of relativity the basic equations could be derived from the equivalence of gravity and inertia. Similarly one can build up quantum theory on the equivalence of waves and particles.

Due however to the desire to seek absolute truth, the *absolutists* have tried to persuade us to accept two different ways of escaping the dilemma of a twofold reality.

(1) The advocates of the wave theory say: Only waves exist; and what sometimes appears to be a particle is in reality the intensity maximum of a group of waves condensed and keeping together within corpuscular dimensions, in violation of the ordinary rules of the wave theory (Schrödinger 1926, later abandoned). Furthermore, what sometimes appears as a discontinuous corpuscular (= quantized) change of energy is in reality the change of energy of a vibration taking place in violation of the continuous laws of damping. (Planck 1900, quantized oscillation.)

(2) The advocates of the corpuscular theory say: Only particles exist, and what sometimes appears to be a maximum of interference is in reality a maximum probability for the occurrence of particles. The particles appear to be guided, at least in their statistical behavior, by wave laws in violation of ordinary mechanics (Born 1927 and now generally accepted).

In § 2 we shall see that both interpretations although they sometimes help to obtain a quick but superficial picture, are untenable from a more critical point of view, in particular in view of the uncertainty principle, which is considered in the present paper from a somewhat different angle. First of all, there is no reason why opinion (1) should be better or worse than opinion (2). The least we should have learned from the dualism of interpretation is this: If one has reason to disagree with waves that have corpuscular attributes, one should reject as well particles that have miraculous wave attributes. Secondly, we are going to show in § 2 that there is no reason to resort to miracles as those postulated in (1) and (2), because one can explain the cases of apparent wave interference as the result of corpuscular collisions; and one can explain those phenomena that seem to prove discontinuous corpuscular changes of energy and momentum as the result of a wave interference. The miracles of quantum theory, so-called to contrast them with the two classical theories, are met only on a higher stage, in dynamics (§ 3).

§ 2. THE KINEMATICS OF DIFFRACTION.

It has often been shown that simple processes like reflection and refraction are understandable as the result of corpuscular mechanics applied to particles, just as well as the result of Huyghens' principle applied to waves. We might study therefore the equivalence of waves and particles in a case that has long been considered as a conclusive argument in favor of the wave theory only, the phenomenon of *diffraction*.

Consider a small line element δx of matter (Fig. 1). A rectilinear monochromatic beam of light coming from the y-direction will then be diffracted by it through a cone $\delta\Omega$ of deflected directions. (We are considering only the coherent part of the deflected light, although in the case of independent gas particles forming the line element it might be that the major part of the incident light is scattered incoherently with change of color.) The coherent cone of diffraction can be accounted for by means of the *wave theory* of light and matter. According to this theory matter is supposed to act as a source of resonance (Huyghens' source) sending out secondary light waves. The length δx of the matter element, the wavelength Λ of the light, and the angle $\delta\Omega$ of the cone of diffraction are then related by the simple formula (giving the order of magnitude):

$$\delta x = \frac{\Lambda}{\delta\Omega}. \tag{1}$$

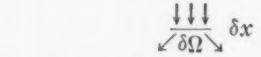

FIG. 1.

The diffraction appears here as a result of the principle of superposition applied to the interfering secondary waves. It seems impossible at first sight to derive the same result without the wave theory.

Nevertheless one can account for the same cone of diffraction by means of the *corpuscular theory* of light and matter. Here photons of momentum P are deflected from their original y-direction. The cone $\delta\Omega$ shows in this interpretation that the matter particles give momentum to the photons up to the amount $\pm \frac{1}{2}P\cdot\delta\Omega$ parallel to the $\pm x$-direction. In

other words the matter particles themselves cover a *range of x-momentum*

$$\delta p_x = P \cdot \delta\Omega \tag{1'}$$

which is the range of their statistically ruled change of x-momentum during the collisions.

One and the same optical signal, the light cone $\delta\Omega$ thus leads us two quite different results concerning the qualities of the matter, depending on the pre-supposed manner of interpretation. According to the wave theory of light the matter is found to consist of a line element of resonance having the length δx. This length might in its turn be interpreted as the width of a packet of matter waves. According to the corpuscular interpretation the same matter consists of particles whose momenta are spread over a range δp_x, that is, which suffer changes of their x-momentum up to that magnitude. The length δx is a quantity derived from the wave interpretation of the signal $\delta\Omega$, the range δp_x belongs to the corpuscular interpretation.

It would be quite a mistake, however, if we should say that the matter *wave* packet spread along δx according to the first interpretation, had the property in addition of giving out momentum of range δp_x. For the momenta have been introduced only in order to explain the deflection of photons of the 2nd interpretation. It would as well be a mistake if we should say that the matter particles [that transmit mechanical momenta of range δp_x] were spread over a range of magnitude δx in space. For δx derives its "reality" only from being the supposed seat of Huyghens' sources of waves. And yet it happens that both opinions, in particular the second one, are so commonly accepted that we may resort to an example from everyday life in order to regain an unbiased judgement.

Suppose we receive a sound signal "eagle"; in the English language this will be interpreted by the picture of a bird of prey. A German, however, will interpret the same sound to mean "Igel," that is, hedgehog. If now we happen to understand both English and German, are we entitled to assume that the source of the sound is a winged hedgehog or a bird with quills?

But this is the very error made by the corpuscular statistical interpretation, that particles are distributed along the range δx, and the same error is repeated by the commonly accepted corpuscular statistical interpretation of the wave density in general. According to the latter it is said, for instance, that the density of the charge cloud around the nucleus of a radiating H-atom is in reality the probability density according to which a corpuscular electron is expected to stay in the various volume elements, in defiance of the laws of mechanics. In fact, the purpose of this charge cloud is merely to account for the frequency and intensity of a wave radiation, and has nothing to do with the corpuscular mechanical interpretation, which is based on transmission of energy and momentum by collisions.

If on the other hand one prefers the picture of the corpuscular electron, one has to endow it with the quality of emitting a photon of energy $\epsilon = E_1 - E_2$, when the electron changes from the energy level E_1 to E_2. But it would be a mistake to ascribe these discontinuities of energy to the aforementioned charge cloud, or to any vibrational state whatsoever. Neither does a jumping electron, which emits or deflects photons of certain energies, call for position governed by a charge cloud, whose only assignment is to send out waves. Nor does a charge cloud, explained as the result of a superposition of matter waves, call for a discontinuous change of its energy.

Instead of striving to acquiesce in such over-interpretations as are contained in the statistical picture of the wave functions, and in the wave picture of discontinuities of energy and momentum, one should say, and it is the meaning of quantum theory to say: The same observed radiation that appears, when interpreted in wave terms, to originate from a rotating or vibrating charge cloud of frequency ν_{12}, seems to originate in energy changes $E_1 - E_2$ of an electron when interpreted in corpuscular fashion. The term "transition density" is expressing this relation in a proper way: Schrödinger's wave density ρ_{12} is the corpuscular equivalent of Bohr's energy jumps, but ρ_{12} is not the place where the particles dwell when carrying out these jumps. A distribution in space is a quality belonging to the wave interpretation of the signal received,

whereas jumps of energy belong to the corpuscular interpretation of the same signal.

Of course, one may ascribe energy and momentum also to waves. One has to be conscious, however, that a *dynamics* of waves is much more specialized and farther removed from direct observation than wave kinematics. On the other hand, one can ascribe to particles a position in space if one resigns fixing this position by means of observations interpreted in a corpuscular fashion.

A similar confusion, only in the opposite direction, can be seen in the case of the well-known wave interpretation of corpuscular discontinuities of energy. Here we mean the opinion, first suggested by Planck, that a particle oscillating with frequency ν_{12} changes its vibrational energy by quantized amounts, emitting thereby a corresponding amount $\epsilon = h\nu_{12}$ of light energy. Instead of defending this compromise between the wave and corpuscular ideas, one should better say; a radiating *oscillator* is from the standpoint of the wave theory, a charge cloud whose vibrating density distribution ρ_{12} can be calculated according to Schrödinger from the superposition of two vibrations of frequency ν_1 and ν_2; the charge cloud sends out light waves of frequency $\nu_{12} = \nu_1 - \nu_2$. From the corpuscular point of view the same "oscillator" has nothing oscillating at all, but is an electron that carries out transitions between energy levels separated by equal steps ϵ. *It would be, however, an over-interpretation if we were to ascribe to the corpuscular electron of the oscillator a distribution in space represented by the oscillating Schrödinger charge cloud, or vice versa, if we should ascribe to the vibration (it is the charge cloud that vibrates) the property of having quantized energy levels and energy jumps.*

It is hard to free ourselves from these incorrect ideas inherited from the older quantum theory, since there are a great number of macroscopic phenomena which, although not proving them, are not disproving them either. But this is due to the fact that macroscopic observations can always be interpreted by means of both classical pictures. For instance, one finds *particles* (better: beams that display corpuscular fluctuations on account of their small intensity, see § 4) which travel to the interference maxima of waves *as though* the

particles were guided by wave rules. We saw, however, that the mechanical cause of this diffraction can be found in collisions with the matter particles. Our example of diffraction explains what is meant when we say: What *is* a matter line of length δx from the wave point of view, *is* an assembly of particles of range δp_x of momentum from the corpuscular point of view.

If the "plug" of matter δx is replaced by a screen with a gap of width δx (this is a description in wave terms) then Babinet's principle requires the gap to produce the same diffracted cone of light $\delta\Omega$ as did the plug. One would expect at first sight that photons (corpuscular theory) should go straight ahead through the gap (wave description), giving a shadow of the edges of δx, instead of being diffracted. The corpuscular cause of their diffraction can be derived from the consideration that what is a plug or gap of width δx in wave terms *are* matter particles of range δp_x in corpuscular terms.

Similar considerations apply to a grating with holes or grooves at constant distances d. This is now a wave description. The corpuscular description of the same grating is this: It represents a system of matter particles bound to surrender momenta ruled statistically in such a fashion that the resulting deflection of photons gives exactly the same pattern as the diffraction of waves. It is the purpose of the quantum theory to give us the mathematical relations between the wave description of a phenomenon and the corpuscular description. In the case of diffraction from a single plug δx, quantum theory gives the result:

$$(1'') \qquad \delta x \cdot \delta p_x = P \cdot \Lambda = h,$$

which follows from multiplying (1) with (1′). That is, the product of the *ranges* δx and δp_x is equal to the product of the *values* of Λ and P of the light employed, and this product always has the same value, Planck's h. The smaller δx, the larger δp_x, where δx and δp_x are complementary results of interpretation of one and the same observation, namely $\delta\Omega$. This is the correct meaning of Heisenberg's uncertainty relation. A more general rule reads: Every change of momentum $p_j \rightarrow p_k$ of free particles carried out with a probability $|a_{jk}|^2$, gives rise to a Fourier component of the corresponding ampli-

tude $\psi(x)$ of the wave density $\rho = |\psi|^2$:

$$\psi(x) = \sum_j \sum_k a_{jk} \cdot e^{2i\pi(p_j - p_x) \cdot x/h}.$$

This rule was already contained in Bohr's *principle of correspondence* of the older quantum theory, and was applied to the diffraction of gratings first by Duane, Ehrenfest, and Epstein. In the case of mutually *bound* particles (waves in higher dimensional spaces), the generalized quantum methods of Born-Heisenberg- Jordan or Schrödinger apply, supplemented in the case of several equal particles by the statistical rules of Einstein- Bose, or Pauli-Fermi- Dirac for particles, and by the rule of symmetry or anti-symmetry for waves.

At any rate there is no need of ascribing to particles, a knowledge of, and obedience to, interference rules, nor for endowing vibrations with corpuscular energy levels or jumps. One has only to make a consistent use of either wave or corpuscular concepts instead of fusing them to a necessarily one-sided and incorrect compromise.[1]

One may see a distinction between the classical theory of a process on the one hand and the wave and corpuscular descrip-

[1] The statistical interpretation appears to be helpful in predicting the probability of emission of α-particles from a calculation of the intensity of the emitted α-wave. In general, however, the α-wave is a superposition of a large or infinite number of monochromatic waves whose phases are chosen so as to cancel their resultant intensity outside the nucleus at the time $t = 0$ and to leave a positive intensity inside only. As time goes on the monochromatic components get out of phase, the intensity outside gains at the expense of the inside, wave beats are rushing outward at group velocity, and the resulting intensity displays interference fluctuations. It would be wrong to assume that the wave intensity with all its maxima and minima and with its beats and fluctuations is measuring the statistical distribution of the α-particles. It is only the *average* intensity over many maxima and minima that is apt to represent the average density of the particles. But this is a very restricted statement as compared with the statistical interpretation of the wave function, which claims that the details and in particular the maxima and minima of the wave intensity describe the average distribution of the particles.

The statistical interpretation fails most strikingly in places xyz where $\psi_n(xyz)$ is finite although the potential energy $V(xyz)$ is larger than the total energy E_n, so the particles at xyz have negative kinetic energy that is imaginary velocity. If it is said that the uncertainty principle allows a large margin of energies to particles in $dxdydz$ this means again that $|\psi_n(xyz)|^2$ does *not* measure the statistical density of particles of energy E_n.

tion on the other. Consider for instance the scattering of α-particles in the field of a nucleus of charge Ze, a process described correctly by Rutherford's formula. (1) The wave theory explains the observed facts by means of a variable index of refraction n that depends on the frequency of the incident α-waves. (2) The corpuscular theory has to derive the same scattered intensity from a system of complementary transmissions of momentum by the scattering particle to the incident particles. (3) Now it is more or less accidental that the same Rutherford formula can also be derived from the model of a Coulomb center Ze that serves to deflect the α-particles $2e$. This coincidence of the classical orbits with the wave and corpuscular result is the reason that we still consider the classical model of a point charge as a kind of physical reality, although it works only in the case of one such point charge. A couple of two classical Coulomb centers would deflect α-particles in a way quite different from the correct result of the wave theory and from its complementary counterpart. This shows again the limited value of the classical model of a point charge quite apart from the dilemma concerning its *radius* when the latter is assumed to be zero or is defined by the electric or the magnetic field energy and the mass. Fortunately the question of the radius neither arises in the wave theory (index n) nor in the description of complementary transmissions of momentum to the incident particles.

§ 3. QUANTUM DYNAMICS.

All that has been said so far about the rational description of an observation by means of waves or corpuscles applies, however, only to a single instant of time. As soon as one follows a certain quantity of matter in time, a new situation arises. One may ask, for instance, for the diameter δx of a quantity of matter at times 0 and t, as derived from an optical observation of the matter. Only if one applies the wave interpretation of the cones of diffraction $\delta\Omega^0$ and $\delta\Omega$ (§ 2) does one arrive at certain diameters δx^0 and δx, to be ascribed to the quantity of matter. Comparing now δx^0 with δx, one finds the surprising result that the diameter δx is

expanding continuously in time according to the formula:

$$\delta x = \frac{h}{m} \cdot \frac{t}{\delta x^0} \quad \text{(expansion of length).} \tag{2}$$

supposed that δx has become already large compared with δx^0. Here it is supposed that there are no forces between the parts of the matter. In formula (2) m is a constant peculiar to the matter, signifying the mass of the molecule in the corpuscular picture, and h is Planck's constant.

The phenomenon of expansion (2) can be accounted for, according to Heisenberg, in a typical quantum fashion, in two distinct steps. *First*, one has to remember that the two diameters δx^0 and δx are *observed* by means of the two diffracted light cones $\delta\Omega^0$ and $\delta\Omega$, from which is inferred

$$\delta x^0 = \frac{\Lambda}{\delta\Omega^0}, \qquad \delta x = \frac{\Lambda}{\delta\Omega}, \tag{3}$$

if the matter is assumed to serve as a secondary source of light waves Λ. One now changes over secondly, in a quite inconsistent manner, to the corpuscular interpretation of the observed light cones. Then $\delta\Omega^0$ means that the photons

$$P = \frac{h}{\Lambda} \tag{4}$$

have obtained at time zero such momenta from the matter, that the matter itself covers a range of initial momenta

$$\delta p_x{}^0 = P \cdot \delta\Omega^0, \tag{5}$$

or of initial velocities up to $v_x{}^0 = \dfrac{\delta p_x{}^0}{m} = \dfrac{P \cdot \delta\Omega^0}{m}$. Thus they will spread during the time t over a length

$$\delta x = v_x{}^0 \cdot t = \frac{P \cdot \delta\Omega^0}{m} \cdot t \quad \text{(expansion).} \tag{6}$$

The expansion (6) proves to be identical with (2), if at the end one returns to the wave intrepretation, that is, if one replaces

$\delta\Omega^0$ and P in (6) by their wave equivalents with the help of (3) and (4).[2]

From this example, which may be considered as the simplest prototype of quantum dynamics, two features of the method of quantum theory can be seen.

First, the act of observation plays a decisive role in determining the process. If, for instance, we say that the matter *is* now within δx^0, and *is* later within δx, we would not be able to give a causal explanation of the miracle of expansion. If, however, we say that the matter is *seen* within δx at time o, we concede the act of being *seen* to be a contributing factor, and *it is true no longer that causality fails* in explaining the expansion (we disregard here the fluctuations which belong to quite a different level of the theory, compare with § 4).

The distinction between *being* and being *seen* is irrelevant in dimensions of everyday life; it becomes essential, however, for microscopic processes where the act of being seen represents a relatively large encroachment into the course of events.

Second, the two diameters δx^0 and δx seen at the times o and t (in fact we see only the light cones and infer from them the lengths δx^0 and δx by means of the wave interpretation) are related to one another in a causal way only by reinterpreting δx^0 by way of $\delta\Omega^0$ into a range of initial momenta $\delta p_x{}^0$ or initial velocities up to $v_x{}^0 = \delta p_x{}^0/m$. The motion lasts for the time t, and leads to the expansion δx, which can be found ultimately only by returning to the wave interpretation of the final cone $\delta\Omega$.

The whole procedure of relating two wave data δx^0 and δx by means of the corpuscular mechanism appears to be very inconsistent, indeed. It represents, however, the typical method of quantum dynamics. Its counterpart consists in relating two corpuscular data by means of wave dynamics. In Schrödinger's theory one considers, for instance, a corpuscular model at times o and t, and one relates the two corpuscular states by means of a wave process, asking in particular for such initial values of the corpuscular energy

[2] From the empirical point of view, it is inconsistent to assign to particles a range in space δx, since δx can be measured only if the wave theory is applied.

that remain constant for all times t (eigenvalue problem, standing wave).

It is quite characteristic of the method of quantum theory that the previously described example of expansion can be inverted. Beginning and ending with the *corpuscular* interpretation of the observed cones $\delta\Omega^0$ and $\delta\Omega$, one finds the miraculous fact that independent particles, which at the time zero are spread over a range $\delta p_x{}^0$ of momenta, *contract* this range to the smaller magnitude

$$(7) \quad \delta p_x = \frac{hm}{\delta p_x{}^0 \cdot t} \quad \text{(contraction of range of momentum).}$$

t is supposed to be large so as to make δp_x small compared with $\delta p_x{}^0$. The relation (7) is equivalent, with (2), as can be seen, if one replaces δp_x by $h/\delta x$ and $\delta p_x{}^0$ by $h/\delta x^0$. In order to explain this contraction in a causal way, one can relate the two corpuscular data $\delta p_x{}^0$ and δp_x by a wave dynamical process, with due consideration of the process of *observing*. For this purpose we first re-interpret the cone $\delta\Omega^0$ in wave fashion, which leads us to the conclusion that the matter represents a group maximum of waves condensed within the range (3) $\delta x^0 = \Lambda/\delta\Omega^0$ in space. According to wave kinematics, such a group maximum spreads out in time with a group velocity v_x which is determined by the formula $v_x = d\nu/d(1/\lambda)$. Here $d\nu$ is the range of frequency, $d(1/\lambda)$ is the range of reciprocal wavelengths of the harmonic components of the wave group. In our present case we have $\delta(1/\lambda) = 1/\delta x^0$, and $\delta\nu = 1/t$, where t is the time of observation, and δx^0 the width of the group maximum. The velocity of expansion of the maximum is thus $v_x = \delta x^0/t$ decreasing with the time t. If one now introduces a wave dynamics in which one ascribes to the wave group a range of *momentum* [3] up to $m \cdot v_x$, where m is a factor characteristic of the substance of the waves, then one

[3] From the empirical point of view it is inconsistent to ascribe a range of momenta to a wave group, since δp_x can be verified only by means of a corpuscular interpretation of the diffracted cone of light. The whole argument is based on grounds just as objectionable as the argument criticised in footnote 2 on page 94. But it represents the ultimate attempt to describe quantum theory in classical terms.

arrives at the range

$$\delta p_x = m v_x = \frac{m \cdot \delta x^0}{t} \tag{8}$$

If this result of wave dynamics is re-interpreted into corpuscular language by replacing δx^0 by $h/\delta p_x{}^0$ it leads to formula (7) for δp_x. In this way quantum theory gives a wave dynamical derivation of the contraction of the range of corpuscular momenta.

It is characteristic that the expansion formula (2), and the contraction formula (3) both contain Planck's h. On the other hand, the two formulæ

$$\delta x = \frac{\delta p_x{}^0 \cdot t}{m} \quad \text{(6)} \qquad \text{and} \qquad \delta p_x = \frac{\delta x^0 \cdot m}{t}, \quad \text{(8)}$$

which relate ranges of length to ranges of momentum, do not contain h. Multiplying (6) by (8) leads to the result that Heisenberg's product (1″) remains constant all the time:

$$\delta x \cdot \delta p_x = \delta x^0 \cdot \delta p_x{}^0 = P \cdot \Lambda = h.$$

We have compared in paragraph § 2 the two interpretations of one and the same optical signal with the English and the German interpretation of a sound signal, "eagle—Igel." If we receive a *succession* of sound signals, they use to represent a reasonable sense only in *one* of the two languages, for instance, the sense "eagle flies high," but the nonsense "Igel, Fleiss, Hai," meaning "hedgehog, diligence, shark." In the case of light signals sent out by matter, it happens, however, that both classical interpretations represent sense. This "sense" is the reason indeed that physicists have developed the corpuscular and the wave theory independently. It appears thus, that there exists a sort of Leibnitzian "prestabilized harmony" between the two classical theories. The assignment of quantum theory is to reveal the formal relation between the two languages. As example of such relations we mention Planck's formula $E/\nu = h$, de Broglie's $p \cdot \lambda = h$, Heisenberg's $\delta p_x \cdot \delta x = h$, Schrödinger's $p_x \rightarrow \frac{h}{2i\pi} \frac{\partial}{\partial x}$.

§ 4. FLUCTUATIONS.

A decisive argument in favor of the pretended corpuscular constitution of matter and light is often seen in the fact that one can *count* particles in a beam. Indeed, at small intensity a beam shows fluctuations *as though* it consisted of particles of a certain mass m or energy E. This argument is contested, however, by the fact that the beam, if its intensity is raised sufficiently, shows fluctuations of a magnitude as though the beam consisted of a group of interfering waves whose phases are distributed at random. The dynamic properties of the ray are determined in both cases by the same material constant m. In the wave theory the role of m can be seen from the example of equation (8) in § 3.

One is confronted then with the fact that in the case of small intensity a diffraction pattern can be calculated by means of the wave theory, and yet shows corpuscular fluctuations. This looks as though "the particles, of which the beam consists in reality, are guided by the interference rules of waves." Here one has forgotten, however, that one could have derived the same pattern by means of corpuscular collisions without employing interference.

Vice versa, after one has derived the diffraction pattern in a corpuscular manner (§ 2), one finds wave-like fluctuations at places of large intensity. This appears then as though "the beam consists in reality of waves whose intensity distribution in the pattern is ruled by corpuscular laws." Here one has forgotten that the same pattern could have been derived from the outset by means of a wave calculation.

Both classical theories fail to give account of the observed intensity and its fluctuations in the case of *intermediate intensities*. Here one starts either with photons which then are subject to the typical wave-like statistics of Bose; or one starts from the wave model of Jeans, and subjects it to the corpuscular statistics of quantized oscillators.

Let us add finally a few remarks on the frequently misinterpreted difference between classical and quantum-theoretical indeterminacy. The latter, as seen from Heisenberg's formula $\delta p_x \cdot \delta x = h$, relates the corpuscular to the wave interpretation of one and the same observation $\delta\Omega$. The indeterminacies of the distribution of particles found in beams of

small intensity, however, have nothing to do with quantum theory, nor have the individual interference beats in rays of large intensity. For instance, if we have a small quantity of radium, we cannot predict the exact times at which single α-particles will escape. This is, however, exactly the same uncertainty as in the case of a small ball put in a large box with a small hole.[4] The task of quantum theory is only to calculate the magnitude of the radium-box in comparison with the magnitude of the hole (Gamow mount) and the energy of the α-ball, starting from certain general ideas concerning the structure of nuclei and applied to the nucleus of number 88. The uncertainty concerning the exact time of emission is then a purely classical affair. The same applies to the exact times of individual beats of α-waves that are emitted from a very strong radium preparation.

[4] In classical statistical mechanics it is the idea that the time of emission depends on particular initial conditions, whereas in the case of α-particles on is not even allowed to have the idea of such initial conditions; observing them would mean changing them.

NOTES FROM THE NATIONAL BUREAU OF STANDARDS.*

ELECTRIC HYGROMETER AND ITS APPLICATION TO RADIO METEOROGRAPHY.

RP1102 by Francis W. Dunmore, in the June *Journal of Research*, describes a new type of humidity-indicating unit for use on radio meteorographs, which operates electrically without appreciable lag. It is a special type of electrical resistor made up of the roughened glass surface between two separate coils of bare wire space-wound on a very thin-walled glass tube. The glass surface may be coated with a dilute solution of lithium chloride which aids the glass surface in absorbing moisture. Experments at various humidities in the temperature range $+30°$ and $-20°$ C. show that a temperature correction must be made. Since it is customary to measure temperature when making humidity measurements, this is easily taken care of.

Two glass hygrometer units with different percentages of lithium-chloride coating may be alternately connected to the transmitting instrument by a fan or motor-operated switch. Each unit may be made to function over a different temperature range, while covering the full humidity scale on the graphical recorder connected to the receiver on the ground. In addition to the two humidity units, a temperature unit and photoelectric cell may be connected into the circuit, thus giving audio notes that give temperature and light brightness (cloud height and thickness).

Flight tests well into the stratosphere, new dual-coil electrical hygrometer in conjunction with the hair hygrometer, showed that the new unit responds almost immediately to changes in humidity, even at high altitudes. The hair unit registered humidity changes some 2 minutes later than the dual-coil units. An ascent rate of 1100 ft./min. was used which caused the hair unit to indicate a humidity change some 2200 feet above the point where the real change took place.

* Communicated by the Director.

MUTAROTATION OF LEVULOSE.

The changes in optical rotation, molecular volume, molecular refraction, and energy content which occur after dissolving levulose and α-*d*-galactose in water clearly show that the mutarotation of levulose is caused by the same kind of reaction as causes the rapid mutarotation of α-*d*-galactose. The similarity of the two reactions and their resemblance to the rapid mutarotation reactions of other sugars is confirmed by the following observations: (1) Alterations in temperature cause large changes in the equilibrium proportions of the labile substances responsible for both the mutarotation of levulose and for the rapid mutarotation reactions. (2) The heat of activation for the reaction representing the mutarotation of levulose is comparable to the heat of activation for the rapid mutarotation reactions. (3) The constants for the mutarotations of levulose and the rapid mutarotation reactions are both extremely sensitive to the catalytic action of acids and bases and vary with pH in like manner.

In the *Journal of Research* for June (RP1104), Horace S. Isbell and William W. Pigman show that the changes which occur during the thermal mutarotation of levulose, lactulose, and turanose are alike for the three sugars and correspond to the changes found in the equilibrium proportions of the labile constituent of galactose under like conditions. The application of "thermal mutarotations" for investigating the mutarotation reactions of sugars which are available only as sirups is illustrated by a study of the "thermal mutarotation" of 2, 3, 6-trimethyl-fructose.

Velocity constants determined in buffered solutions covering the range between pH 1 to 7 are reported for the mutarotations of glucose, galactose, and levulose. For the rapid reactions, the catalytic effects of hydrogen and hydroxyl ions are much greater than those found for the normal alpha-beta pyranose interconversion. The high sensitivity of the rapid mutarotation reactions to variations in acidity accounts for some of the discrepancies in the mutarotation constants obtained by using distilled water containing variable quantities of carbon dioxide. Hence, for accurate measurements the acidity must be controlled. The mutarotation constants

found for α-*d*-galactose and β-*d*-galactose in buffered solutions were the same within the experimental error.

Attention is directed to the observation of Hudson that the mutarotation of the fructose liberated from sucrose by invertase occurs at the same rate as the mutarotation of levulose, but in the opposite direction. Since the fructose constituent of sucrose is a furanose, and levulose is a pyranose, the mutarotation of fructose set free by invertase must be caused by the conversion of part of the freshly liberated fructofuranose to levulose. The mutarotation of levulose, which is the reverse, must be caused by the conversion of part of the freshly dissolved sugar to the fructofuranose. This conclusion leads to the following deductions: (1) That the mutarotation of lactulose is caused by a furanose-pyranose change and that crystalline lactulose is a furanose. (2) That the mutarotation of Hibbert's 1, 3, 4-trimethyl-fructofuranose results from a furanose-pyranose change and that the sugar is properly classified as a furanose. (3) That the mutarotation of turanose results from a pyranose-furanose change and therefore the glucosido group is not united with the fifth or sixth carbon but in all probability it is united with the third carbon. (4) That the rapid reactions characteristic of the complex mutarotations of galactose and other sugars are pyranose-furanose interconversions and the complex mutarotations arise from the establishment of an equilibrium between the furanoses and the normal α- and β-pyranoses.

ANALYSIS OF DENTAL GOLD ALLOYS.

Approximately 41,000 troy ounces of platinum metals, chiefly palladium and platinum, valued at approximately $1,243,000, are sold yearly to the dental industry by refiners in the United States. The quantity of gold, the chief constituent of these alloys, is far greater, but no figures are available for it. Silver, to the extent of two per cent. of all that is used industrially, likewise, is an essential constituent of dental gold alloys.

Raleigh Gilchrist of the Bureau's Chemistry Division has recently developed a new method for determining the composition of dental gold alloys which can also be applied, with

slight modification, to the analysis of crude platiniferous materials and to the refining of metallic waste such as dental and jewelry scrap. The chief feature of the method is the collective separation of base or non-precious metals from gold and the platinum metals. Gold is precipitated by the reducing action of sodium nitrite, and a new technic for removing tin, prior to the precipitation of gold and to the subsequent collective precipitation of other base metals, is included. The platinum metals are converted to complex nitrite compounds which do not precipitate.

Used as an analytical procedure for dental gold alloys, the method provides for the separation and gravimetric determination of silver, iridium, tin, gold, paladium, rhodium, platinum, indium, copper, zinc, and nickel. Since cobalt, manganese, chromium, and iron are quantitatively precipitated under the conditions which are specified for the collective precipitation of indium, copper, zinc, and nickel, the method can be applied to the analysis of other types of precious metal materials such, for instance, as native grain platinum.

Used as a refining process, the method effects a rapid and clean separation of gold in a form which is easily handled. It greatly simplifies the recovery of the valuable platinum metals.

The complete details of the method are given in RP1104 in the *Journal of Research* for June.

THERMAL EXPANSION OF HEAT-RESISTING ALLOYS.

RP1106 by Peter Hidnert, in the June *Journal of Research*, gives results of an investigation of linear thermal expansion and effects of heat treatments on the growth, density, and structure of an iron-chromium-aluminum alloy and three iron-chromium-aluminum-cobalt alloys. Coefficients of linear expansion for various temperature ranges between 20° and 1000° C. were obtained. No polymorphic transition was observed in these alloys between 20° and 1000° C. They exhibited growth (0.82 to 2.81 per cent.) after various heat treatments at temperatures up to 1400 ° C. Additional heat treatments would probably cause additional growth. The

densities of the mechanically worked iron-chromium-aluminum alloy and iron-chromium-aluminum cobalt alloys increased 1.12 to 2.50 per cent. as a result of various heat treatments to 1400° C. Tremendous grain growth occurred in the alloys as a result of various heat treatments at elevated temperatures.

EFFECT OF COPPER AND IRON ON LEATHER.

The deterioration of leather is accelerated by the presence of copper or iron. Most vegetable-tanned leathers contain small amounts of these metals as impurities, the source of which is the tanning materials, which become contaminated while in contact with the grinders and evaporators used in their preparation. The acidic character of leather causes a further contamination if contact is made in service with surfaces containing these metals, leathers used for belting and hydraulic packings being particularly susceptible to such attack.

An investigation by Joseph R. Kanagy, described in RP1109 in the June number of the *Journal of Research*, was undertaken to obtain some conclusive evidence on the deteriorative effects of copper and iron, thus making possible a more accurate interpretation of data obtained during accelerated aging of leathers in the oxygen bomb. A more detailed knowledge of the effect of these metals on leather deterioration is of interest to the tanner, to the manufacturer of leather-making materials, and to the consumer who uses leathers in service where contact is made with metallic surfaces.

In this investigation, chestnut- and quebracho-tanned leathers were impregnated with different amounts of various salts of copper and iron and exposed to an atmosphere of oxygen in a bomb at 100° C. and 100 lb./in.^{2}. The amount of copper or iron in the leathers varied from 0.01 to 0.78 per cent. The extent of the deterioration in the presence of these metals was determined from the percentage of the total nitrogen extractable from the exposed samples, which increases with continued deterioration. All leathers containing copper showed deterioration, which increased with an increase in copper content. The rate of increase was most rapid for amounts less than 0.2 per cent. In the case of iron no ap-

preciable increase in the rate of deterioration was observed in leathers having pH values above 3.5 where acidity is low. With pH values less than this, deterioration was a function of pH rather than of iron content.

PHYSICAL CONSTANTS OF RUBBER.

A critical survey of the published values for sixteen of the principal physical constants of rubber was presented by Lawrence A. Wood of the Bureau's rubber section at the World Conference on Rubber Technology, which met in London, May 23–25. The properties considered were selected for their scientific interest rather than for their technical importance, as follows: Thermal constants—thermal conductivity, specific heat, heat of fusion of crystalline rubber, and heat of combustion; mechanical constants—compressibility, Poisson's ratio, and the velocity of sound; optical constants—refractive index, dispersion, and stress-optical coefficient; electrical quantities—dielectric constant, power factor, and conductivity; other constants—dimensions of the unit cell, the density, and the expansivity.

All published values of these sixteen basic physical constants were considered. The value for each constant which seems to be the most reliable was indicated, having been corrected (when necessary) to the standard conditions of normal atmospheric pressure and temperature of 25° C. Consideration was given to rubber in four different forms: The purified hydrocarbon, commercial crude rubber, soft vulcanized rubber containing 2 per cent. combined sulphur, and ebonite containing 32 per cent. combined sulphur.

The survey indicates that there are significant gaps in the present knowledge of the fundamental properties of rubber. In some cases data are completely lacking, while in many others the best values available are not of the accuracy required for present-day scientific and industrial work. Even in cases where the constants have been measured with evident care, many of the values represent the result of a single investigation, and hence should be subjected to independent confirmation. The summary of selected values of the different constants may, therefore, serve as a basis for the planning of future investigations.

THE FRANKLIN INSTITUTE

COMMITTEE ON SCIENCE AND THE ARTS.

(Abstract of Proceedings of Stated Meeting held Wednesday, June 8, 1938.)

HALL OF THE COMMITTEE,
PHILADELPHIA, JUNE 8, 1938.

MR. EDWARD L. FORSTALL *in the Chair.*

The following report was presented for final action:

No. 3037: Work of Newcomb K. Chaney on Activated Carbon.

This report recommended the award of the Howard N. Potts Medal to Newcomb Kinney Chaney, of Philadelphia, Pennsylvania, "In consideration of his original and successful work in the hitherto uncharted field of carbon activation."

JOHN FRAZER,
Secretary to the Committee.

LIBRARY NOTES.

The Committee on Library desires to add to the collections of the Institute any technical writings of members who have had occasion to publish such material.

Literary contributions from author-members will be gratefully acknowledged, properly inscribed and noted in the Journal of the Institute.

Photostat Service. Photostat prints of any material in the collections can be supplied on request. Orders received in the morning are filled the same day. The average cost for a print $8\frac{1}{2} \times 11$ inches is thirty-five cents.

The library and reading room are open daily from nine o'clock A.M. until five o'clock P.M. Saturdays until 12 o'clock noon. 645 readers made use of the facilities during the twenty-five days of May.

RECENT ADDITIONS.

Agriculture.

PFEIFFER, EHRENFRIED. Bio-Dynamic Farming. 1938.

Architecture and Building.

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BOOK REVIEWS

PHOTOELEMENTS AND THEIR APPLICATION, by Dr. Bruno Lange, translated by Ancel St. John. 297 pages, illustrations, 15 × 23 cms. New York, Reinhold Publishing Corporation, 1938. Price $5.50.

Of all the sources of electric current including the magnetic field, heat, and chemical sources, that from light is the newest. Like its predecessors it is difficult to trace the evolution of light as a source of electric current from its very beginnings, but the manifold uses of the present state of the subject indicate it is quite possible that new vistas will be opened which may make revolutionary changes in manufacturing and even affect to a considerable extent the everyday life of everyone. It is very apparent therefore that interest in the photoelements is emerging with rapidity from the purely academic.

This book has for its purpose a presentation of the photoeffects both internal and external, the physical properties of photoelements, and methods of measurement. At first the reader is made acquainted with the basic photoelectric phenomena and the historical developments. This leads to a consideration of various theories concerning the semiconductor effect in which there is calculated the open circuit potential of a photoelement, and the physical properties of semiconductor photocells wherein among other things it is shown how far the experimental facts agree and the exact course of the photocurrent, the photopotential and the cell resistance in relation to the intensity of illumination. This concludes the first part of the book. At this point a bibliography of periodical and book literature is attached.

Part two gives a survey of the status of the technical uses of photoelements. First the construction and performance of the photoelements is taken up. This is followed by descriptions of illumination meters, exposure meters, special photometric apparatus, the mechanical transmission of indications to a distance using light rays and photocells, amplifying equipment, photoelectric switching and signal devices, and uses in various fields of activity. There is a bibliography appended to this section also.

Written by one who has contributed in no little degree to this field of endeavor, and admirably translated from the original German into English, the book is a clear treatment of the present state of the subject.

R. H. OPPERMANN.

GRIMSEHLS LEHRBUCH DER PHYSIK, neubearbeitet von Prof. Dr. R. Tomaschek. Zweiter Band, Zweiter Teil, 456 pages, illustrations, 15 × 23 cms. Leipzig, B. G. Teubner, 1938. Price 10.50 marks.

This book is one part of a set of texts on Matter and Ether and is devoted expressly to the higher physics of the construction of matter. That this subject is contained in the foremost ranks of present day investigation is well known and the results of the past few years have brought to light much new knowledge. It is the intention of the book to present the various aspects of this new knowledge so that a foundation of fundamentals may be laid.

It is divided into eleven parts. Starting with the electrical composition of matter the student is lead through treatments on radioactivity, the cathode ray effect on matter, and the reciprocal effect of short electromagnetic waves. This is followed by discussions on the nucleus of the atom, and matter with relation to light which has very interesting expositions on temperature waves, fluorescence and phosphorescence. The spectrum and the structure of the atom in a poly-electron system, the construction of molecules, the structure of connected matter, are all treated in a most thorough manner. Under the heading of geophysical problems of electricity and magnetism an explanation is given which should have much appeal to those interested in atmospheric phenomena. Here static electricity above the earth is considered as well as the earth's magnetism.

The main feature of the book is its thoroughness. Diagrams, curves, tables, and illustrations appear profusely throughout. Comprehensive name and subject indexes add greatly to its value for reference.

R. H. OPPERMANN.

EARTH-LORE, GEOLOGY WITHOUT JARGON, by Professor S. J. Shand. 144 pages, plates, illustrations, 14 × 20 cms. New York, E. P. Dutton & Co., Inc., 1938. Price $1.25.

This little book is rather more than an elementary sketch of geology intended for the lay reader. While it is very simply written, instructive and an enormously condensed treatise about the structure of the earth it may not be altogether intelligible to those who have little or no knowledge of the fundamental principles upon which geology is based, it is however, a readable book from beginning to end. For those possessing a so-called liberal education it affords a quite simple and understandable elucidation of general geological phenomena.

Geologists are often asked and ask themselves, why is it so little of the history of the planet upon which we live and have our being is taught in our high schools and colleges, in fact unless a student specializes in that subject he or she may graduate knowing less of the history of the earth than of ancient Greece and Rome, in other words are the mutations and permutations of human existence all a student needs to know of history when going out into the world as a liberally educated person. Surely the record of the earth's creation, growth and physical development, not to mention the beginnings and expansion of life upon it, are of equal importance and by no means secondary.

This is understandable when one considers that geology as a science is not much more than a century old. Speculations regarding the earth began with the old Grecian philosophers and continue to our present time just as astrology, a subject of the most grotesque ignorance, still endures among those who should know better.

The Mosaic Cosmos of our fathers and grandfathers sufficed to explain to them the beginnings of things. To us of the present generation the Book of Genesis in its early chapters means little more than one of the most beautiful poems ever written by inspired man. Professor Shand disposes of such old revered, beliefs that sufficed for our forefathers, by the irresistible logic of modern scientific knowledge and research. He also disposes of the more modern postulate of "Atlantis and Other Lost Continents" with equally convincing reasoning. But when he discusses the new and in most respects astonishing Wegenerian hypothesis of "Drifting Continents" the lay reader is likely to become bewildered and quite skeptical, although to many, if not most, geologists the theory is neither illogical nor fantastic.

On the whole this little book is to be highly commended; its careful perusal should enable any educated, intelligent reader to acquire a good general knowledge or idea of how this old earth is made up. He may learn from it in a very general manner how geophysicists have tried, in a very ingenious way, to determine something of its interior. He will be told a bit about the alphabet that constitutes the words written on the pages of the book of rocks, the paleontological and zoological record of an ancient world millions of years ago, and that rocks themselves are not necessarily voiceless stones, but complex, compound bodies recording the sequence of past life and events upon the only member of our planetary system in which life can exist. The reader will be told how muds develop into slates and shales, how corals and mollusks become limestones, how sands and gravels are changed to sandstones, conglomerates and quartzites and so on through the whole gamut of lithic development including the magmas from the plastic interior of

the earth which, upon cooling and hardening, become our granites, porphyry, basalts, etc.

F. LYNWOOD GARRISON.

A SHORT HISTORY OF NAVAL AND MARINE ENGINEERING, by Eng. Capt. Edgar C. Smith. 376 pages, plates, illustrations, 15 × 24 cms. Cambridge, Babcock and Wilcox, Ltd., 1937.

Undoubtedly one of the great factors which influenced the progress of civilization has been marine engineering. Its importance has extended through engineering to a redesign and construction of the ships themselves and today the high speeds, large size, and superb comfort of the transatlantic liners is a monument to which marine engineering is closely allied.

The author of this book has devoted his life to marine engineering and many years in gathering material for the history. Some of it he has published in the English periodical *Engineering* and some has never appeared before. It is a story that traces the development of the steam boat from its birth, through its pioneer stages to the present time. It is interesting to note in the beginning of the book there is stated, "Though it would be wrong to neglect what was done in the United States, the progress of marine engineering was mainly due to the work of British engineers," and later, "The practicability of the application of the steam engine to boats was demonstrated almost simultaneously in America, Scotland, and France."

The book is of a popular character, written in understandable language. Both marine engineering of war craft as well as in commerce are covered and there is some portion devoted to the marine internal combustion engine. The sixteen plates shown add much in value to the book. Anyone who wishes to become informed in this subject and, at the same time, desires interesting reading will do well to read this book.

R. H. OPPERMANN.

A FIRST COURSE IN PHYSICS FOR COLLEGES, by Robert Millikan, Henry Gale and Charles Edwards. Revised Edition, 712 pages, plates, tables, illustrations, 14 × 21 cms. Boston, Ginn and Company, 1938. Price $4.00.

This is the second edition of a text which has had extensive use, the first having been published in 1928. In it the authors have endeavored to incorporate in fundamental physical theory the new advances in the field, new practical applications of physical knowledge, and a new plan of presentation to suit the needs resulting from recent changes in secondary educational methods. That there is a need for a text containing these features cannot be doubted. The subject of physics has been and is in a state of flux, and those who have followed a prescribed course in physics years ago will have difficulty in recognizing the present sequence of study and procedure to follow.

According to the number of pages in the book (712) it is voluminous. An examination of it reveals, however, that a great deal of space is taken up in interesting practical everyday applications of physics in the way of descriptive matter and a large number of illustrations so that instead of a dry difficult drudge there is an interesting and informative book on things that make for greater appreciation of life. The subjects of mechanics and heat, electricity and magnetism, light and

sound, and the atomic structure are all treated in this manner. Throughout the book the illustrations and descriptions are of so simple and fundamental a nature that inspiration to thoroughly master the text must result. They include such achievements in physics as the details of a submarine, the cream separator, a modern power plant, and sections of a modern automobile. This material of interest creation is so interspersed with the actual technical information that at times it is difficult to separate it. With regard to the latter there is used the step-by-step solutions of problems to make for greater clarification of various points. At the end of each chapter there are given a number of problems for solution, the answers to which can be found in the back of the book. In addition to these there is a list of test questions which can usually be answered by giving descriptions instead of working out or computing answers.

The subject of physics, by its very nature requires a knowledge of mathematics. This book, while it is only intended as a first course, is an admirable exposition in this respect to the application of mathematics in a practical way, rather than as a means of obtaining explanations and solutions in mere figures. The book reveals a keen insight into the nature and needs of the student. It is also a revelation as well as a good reference work for more mature readers.

R. H. OPPERMANN.

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS.

Report No. 621, Compressible Flow about Symmetrical Joukowski Profiles, by Carl Kaplan. 15 pages, illustrations, 23 × 29 cms. Washington, Government Printing Office, 1938. Price 10 cents.

The method of Poggi is employed for the determination of the effects of compressibility upon the flow past an obstacle. A general expression for the velocity increment due to compressibility is obtained. This general result holds whatever the shape of the obstacle; but, in order to obtain the complete solution, it is necessary to know a certain Fourier expansion of the square of the velocity of flow past the obstacle. An application is made to the case of a symmetrical Joukowski profile with a sharp trailing edge, fixed in a stream of velocity v_0 at an arbitrary angle of attack and with the circulation determined by the Kutta condition. The results are obtained in a closed form and are exact insofar as the second approximation to the compressible flow is concerned, the first approximation being the result for the corresponding incompressible flow. Formulas for the lift and moment analogous to the Blasius formulas in incompressible flow are developed and are applied to thin symmetrical Joukowski profiles for small angles of attack.

Since actual experimental data for Joukowski profiles are lacking, the theoretical results are applied to a thin and a thick profile at zero angle of attack, and the velocity and pressure distributions are calculated and compared with those for the corresponding incompressible cases. The critical values for the ratio of the stream velocity v_0 to the velocity of sound in the stream c_0, corresponding to the attainment of the local velocity of sound c by the fluid on the surface of the airfoils, are also obtained.

Report No. 622, A Photographic Study of Combustion and Knock in a Spark-Ignition Engine, by A. M. Rothrock and R. C. Spencer. 21 pages, illustrations, 23 × 29 cms. Washington, Government Printing Office, 1938. Price 10 cents.

A photographic study of the combustion in a spark-ignition engine has been made, using both schlieren and flame photographs taken at high rates of speed. Although shock waves are present after knock occurs, there was no evidence of any type of sonic or supersonic compression waves existing in the combustion gases prior to the occurrence of knock. Artificially induced shock waves in the engine did not in themselves cause knock. The photographs also indicate that, although auto-ignition ahead of the flame front may occur in conjunction with knock, it is not necessary for the occurrence of knock. There is also evidence that the reaction is not completed in the flame front but continues for some time after the flame front has passed through the charge.

Report No. 623, A Study of the Torque Equilibrium of an Autogiro Rotor, by F. J. Bailey, Jr. 10 pages, illustrations, 23 × 29 cms. Washington, Government Printing Office, 1938. Price 10 cents.

Two improvements have been made in the method developed in N.A.C.A. Reports Nos. 487 and 591 for the estimation of the inflow velocity required to overcome a given decelerating torque in an autogiro rotor. At low tip-speed ratios, where the assumptions necessary for the analytical integrations of the earlier papers are valid, the expressions therein derived are greatly simplified by combining and eliminating terms with a view to minimizing the numerical computations required. At high tip-speed ratios, by means of charts based on graphical integrations, errors inherent in the assumptions associated with the analytical method are largely eliminated.

The suggested method of estimating the inflow velocity presupposes a knowledge of the decelerating torque acting on the rotor; all available full-scale experimental information on this subject is therefore included.

COMBUSTION, FLAMES AND EXPLOSIONS OF GASES, by Bernard Lewis and Guenther Von Elbe. 415 pages, illustrations, 14 × 22 cms. New York, The Macmillan Company, 1938. Price $5.50.

This is a title that covers a multitude of subjects. Probably because of this there has been little accomplished toward a complete investigation on a broad front, and by far what work of the nature of an investigation that has been done, in recent years at least, has been recorded mainly in periodical and society publications which include only specialized treatments of the general subject. Consequently knowledge of certain parts of the subject has advanced to the point of arriving at definite conclusions while on others it has lagged to the extent of being still in the controversial stage. Also workers in the field encounter difficulties in the way of literature searches. It is therefore gratifying to see a book which attempts to combine the loose ends into a whole.

The book is divided into four parts. The first is on the chemistry and kinetics of the reactions between fuel gases and oxygen. The ignition of a combustible gas mixture caused by a self-accelerating chemical reaction that takes

place simultaneously throughout a volume of gas subjected to certain conditions, such as heat, compression, electric discharge, etc., is an inseparable part of this division. The reaction between hydrogen and oxygen, carbon monoxide and oxygen, hydrocarbons and oxygen, and the emission spectra and ionization in the flame front are all given adequate consideration. The second part of the book is under the heading of propagation of flames. It begins with a treatment on the limits of self propagation of flames and then devotes considerable space to the interesting topic of flame photography both by direct and by the schlieren methods, and the measurement of pressure rise in closed vessels. Then spherical and stationary flames are discussed followed by the theory of the burning velocity, diffusion flames, and detonation. Flames in electric fields is only briefly mentioned. The subject is a special one and contributes little to the understanding of combustion. The interested reader is referred to a list of literature references.

Part three is devoted to the state of the burnt gas. This comprises studies of the establishment of thermodynamic equilibrium in the burnt gas and of the causes of departure of the actual from ideal adiabatic combustion. The last part of the book examines the combustion process in the Otto and Diesel engine. There are three appendices giving data for thermochemical calculations, limits of inflammability and flame temperatures.

The authors have done a remarkable work in presenting here up-to-date knowledge of this field so compiled as to follow a logical trend. They have offered appraisals of existing thoughts and conclusions some of which are controversial but which have a great deal of authoritativeness. The book should be of great value to workers in this field and should stimulate further investigation.

R. H. OPPERMANN.

TODAY'S GEOMETRY, by David Reichgott and Lee R. Spiller. 379 pages, illustrations, 15 × 23 cms. New York, Prentice-Hall, Inc., 1938. Price $1.84.

There are many subjects for study necessary for a scientific background that are difficult and dull because of the method in which they are presented. Students continue to question their pertinency and value which leads to either a half hearted interest or just interest enough to obtain sufficient knowledge to pass examinations. Then the knowledge gained is quickly forgotten. In spite of the fact that mathematics is the foundation of science the condition exists with this subject particularly. Of recent years a great deal of effort has been expended to correct this condition by elaborating textbooks so that the application of the subject to practice is forceably illustrated. One of such attempts is "Today's Geometry."

At the outset there is explained what geometry is and the value of it with respect to almost any kind of work. This is, in itself, illuminating and serves to create interest. The text continues along these lines covering triangles, locations of points, polygons, ratio and proportion, the circle, solids, and the solution of right triangles by trigonometry. The last chapter is devoted to what is called "Problems in Industry." Here there is discussed what is practical accuracy of measurements in different kinds of work such as in lumber, and machine work; how geometry plays its part in the engineering of structures such as the Lincoln Tunnel under the Hudson River, and the New York World's Fair.

The book is well written and profusely illustrated. Students of high school grade would receive a thorough foundation in a very important subject by studying it.

R. H. OPPERMANN.

DUODECIMAL ARITHMETIC, by George S. Terry. 300 pages, tables, diagrams, 25 × 30 cms. New York, Longmans Green and Co., 1938. Price $7.50.

Very few of us, except those who are mathematicians, ever give a thought to the possibility of using other arithmetical systems to advantage over our own which is based on the system of ten's. Yet we often use other systems such as in the linear measure units of feet and yards where the base is twelve, and in the case of the English monetary system of pounds and shillings. Would not twelve be a better base than ten? Mr. George S. Terry believes it has many advantages and endeavors to explain them in this book. "Ten," he says, "was a convenient base when calculation meant adding small heaps of little stones. This stage has long since passed, yet we are still apt to think that there is some quality possessed by the number ten which produces the advantages of the decimal point and of the decimal form of fractional representation." Of the eleven fractions from one-half to one-twelfth, five can be expressed exactly by a one-place duodecimal (using twelve as a base), two by two-place decimals—seven in all. Decimally, three can be expressed exactly by one place, one by two places, and one by three places—five in all.

In order to use one dozen as the base for arithmetic two new integers are introduced. After counting up to nine, they are *X* and *E*, and the number ten follows them. One dozen is then written as 10. One dozen and a half are represented by 16, namely one dozen and six units. One-quarter is .3, and one-third is .4, three times four is 10.

Flexibility is the fundamental advantage of the system. The advantage of twelve as a base over eight or sixteen is that it divides into three as well as into four. The duodecimal multiplication table is easy to learn and easy to use because of the consistent endings of the three, four, six, eight and nine times. Mr. Terry explains in his book clearly how the system works with regard to fractions, factorials, reciprocals, interpolations and the advantages gained in each instance. Tables are included for the conversion from the decimal to duodecimal and vice-versa, powers, squares and cubes, angles, natural functions, logarithms, etc. The book is well worth giving consideration.

R. H. OPPERMANN.

KENT'S MECHANICAL ENGINEERS' HANDBOOK. DESIGN. SHOP PRACTICE. Eleventh Edition, rewritten by Robert Thurston Kent. 1378 pages, illustrations, tables, 14 × 22 cms. New York, John Wiley & Sons, Inc., 1938. Price $5.00.

This is the last of the present edition of the series of electrical and mechanical handbooks, produced by this publisher, to make its appearance. It is the second part to the well known "Kent's Handbook," and is devoted exclusively to design and shop practice with the exception of what duplicated material from the other volumes is unavoidable in order that the volume be complete in itself. There are some twenty-eight sections on metallic and non-metallic materials, mechanism

and mechanics, lubricants, vibration and noise, structures, foundry and forging practice, machine and woodworking shops, materials handling, mechanical power transmission, electric motors, safety engineering, and mathematical tables. There is much new material and some of the older information is given in greater detail. Those to whom "Kent's" has been a by-word and younger engineers new in practice will do well to examine the great mass of information here given for their use.

R. H. O.

A TEXT-BOOK ON CRYSTAL PHYSICS, by W. A. Wooster. 295 pages, illustrations, 14 × 22 cms. New York, The Macmillan Company, 1938. Price $4.00.

Crystal Physics is a text on the fundamentals of a subject that is rapidly entering many diverse fields. It has not been very long ago when crystals were not very important commercially except as jewels, and even then certain properties were known but held of little practical use. The demands of industry however spurred research in this important field until now workers in many endeavors who have not had a thorough elementary training in this subject feel the need of the new knowledge. Consequently also, the subject is being covered more or less in many colleges and universities. The book at hand is a text for such students and others who have had the proper educational background.

The author states that a two-fold object has been kept in view—to present the classical treatment of the physical properties of crystals in terms of tensor notation and also to indicate the lines of development of modern theoretical and experimental research. The first chapter deals with the application of tensor notation to crystal physics. In this there is discussed the transformation of vectors, and second and higher order tensors; the operations of symmetry; the physical properties of crystals represented by triaxial ellipsoids. The next division considers the thermal expansion and the homogeneous deformation of crystals. Homogeneous deformation means that all lines which were straight before deformation are straight afterwards. This in itself has evoked an enormous amount of inquiry especially because of the demand for metals and alloys with particular properties in recent years. Passing from this subject the student is taken to the general theory of conduction in crystals covering thermal and electrical conduction. The results of recent research on the conducting properties of electrical insulators and the photoelectric and rectifying properties of certain crystals, according to the author, have not been sufficiently systematized to be included here. The effect of the magnetic field on different crystals is given interesting treatment.

The application and theory of piezo-electric oscillations forms an important part of the book as there are covered the limitations imposed on the piezo-electric moduli by the crystal symmetry, experimental methods of measuring piezo-electric moduli, qualitative methods of detecting piezo-electricity, etc. Pyro-electricity is studied which affords a means of determining the presence or absence of a center of symmetry. This diagnostic test is almost the only practical application of the knowledge about pyro-electricity. The final chapter of the book is devoted to the topic of elasticity which has been examined theoretically to a considerable extent but, in spite of this, experimental data are meager.

The text on the subjects covered is quite well done. Throughout the work

there is reflected a keen insight to the situations of students, especially their condition of training. An example of this is the elimination of some modern concepts on account of the requirement of greater mathematical knowledge than is presupposed. The book fulfills its purpose well and should be considered by prospective students of the subject.

R. H. OPPERMANN.

ENGINEERING ELECTRONICS, by Donald G. Fink. First Edition, 358 pages, illustrations, 15 × 23 cms. New York, McGraw-Hill Book Company, Inc., 1938. Price $3.50.

The progress of electronic methods has been so rapid that it has been equaled by few other branches of applied science. Further, there is no indication as yet that it has reached its zenith. In the fields of radio and manufacturing, applications are ever increasing. Many electrical engineers who have had little or no training in electronic principles are beginning to feel the need of such knowledge. Engineering Electronics was written for this purpose. The author, Managing Editor of Electronics, has had considerable experience in this field and the work is authoritative.

In the introduction a preliminary survey is given of electronics in engineering. This is brief and to the point, covering electrical engineering in all its phases, both in power and communication. The multitude of services of the electron tube as a measurement and control device as well as its photosensitive application is briefly mentioned. There is also a resume of basic ideas of principles of electronic action followed by an introduction to the terminology of the subject.

From here the book is divided into three parts. The first is devoted to physical electronics which generally gives an understanding of electronic conduction, its capabilities and limitations. Here the atomic nature of electricity is discussed, the production of electrons, the control of them in vacuum, and electron currents in gases and vapors. Electron tubes is covered in the second part of the book. Familiarity is here given with thermionic, gas-filled tubes, and photosensitive tubes and cells. The section on gas and vapor filled lamps is of extreme interest in view of the great amount of research now being done by lamp companies and the promise of this type of lamp emerging from small to great commercial importance in the way of providing more efficient and cheaper light for longer periods. The highly ingenious applications of electron tubes is described under the heading of Specialized Electron Tubes. The cathode ray tube, the X-ray tube, the iconoscope, electron image tubes, multiplier tubes and the ionization gauge illustrate the remarkable range of the present day uses of the free electron and indicate some of the probable uses in the future.

Electron-tube applications, which is the title of the third part of the book, gives a knowledge of circuits in which electron tubes are applied. It begins with a treatment on elements of circuit theory and then goes into power transformation circuits, communication circuits, and industrial control and measurement circuits. There are exercise problems at appropriate places in the book, the answers to which are given in an appendix. Finally there is a subject index.

The book is a practical one. Extreme sympathy with the needs of the busy practicing engineer is exhibited throughout. The author's plan and method of presentation should make a demand for the book.

R. H. OPPERMANN.

PUBLICATIONS RECEIVED.

Kent's Mechanical Engineers' Handbook. Design. Shop Practice. Eleventh Edition, rewritten by Robert Thurston Kent. 1378 pages, illustrations, tables, 14 × 22 cms. New York, John Wiley & Sons, Inc., 1938. Price $5.00.

Negative Ions, by H. S. W. Massey. 105 pages, illustrations, 14 × 22 cms. New York, The Macmillan Company, 1938. Price $1.75.

Introduction to College Physics, by Clinton Maury Kilby. Second Edition, 398 pages, illustrations, 14 × 22 cms. New York, D. Van Nostrand Company, Inc., 1938.

Applied Thermodynamics, by Virgil Moring Faires. 374 pages, illustrations, 15 × 23 cms. New York, The Macmillan Company, 1938. Price $3.90.

Problems on Applied Thermodynamics, by Virgil Moring Faires and Alexander V. Brewer. 137 pages, tables, diagrams, 15 × 23 cms. New York, The Macmillan Company, 1938. Price $1.40.

Probleme der Technischen Magnetisierungskurve, Vorträge Gehalten in Göttingen im Oktober 1937, herausgegeben von R. Becker. 172 pages, illustrations, 16 × 24 cms. Berlin, Julius Springer, 1938. Price 16.50 Marks.

The Fine Structure of Matter, The Bearing of Recent Work on Crystal Structure, Polarization and Line Spectra, being Volume II of a comprehensive treatise of atomic and molecular structure. Part II: Molecular Polarization, by C. H. Douglas Clark. 312 pages, illustrations. Part III: The Quantum Theory and Line Spectra, by C. H. Douglas Clark. 256 pages, illustrations. Two volumes, 15 × 22 cms. New York, John Wiley & Sons, Inc., 1938. Price $4.50 each.

Der Smekal-Raman-Effekt, erganzungsband 1931–1937, von Dr. K. W. F. Kohlrausch. 288 pages, illustrations, 14 × 22 cms. Berlin, Julius Springer, 1938. Price 24 Marks.

On Understanding Physics, by W. H. Watson. 141 pages, 14 × 22 cms. New York, The Macmillan Company, 1938. Price $2.25.

Elementary Thermodynamics, by Virgil Moring Faires. 219 pages, illustrations, 15 × 23 cms. New York, The Macmillan Company, 1938. Price $2.60.

Edward Wilson: Nature-Lover, by George Seaver. 221 pages, illustrations, plates, 14 × 23 cms. New York, E. P. Dutton & Co., Inc., 1938. Price $3.00.

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CURRENT TOPICS

Transmutation of Chemical Elements and the Atomic Nucleus.—At a luncheon of the Eta Kappa Nu, the honorary electrical engineering society, at Rosoff's restaurant in New York City recently PROF. VLADIMIR KARAPETOFF, professor of electrical engineering at Cornell University, pointed out the importance of electrical engineers in becoming acquainted with the recent theories of the structure of the atomic nucleus based upon successful transmutation of many chemical elements into one another. Apart from the academic interest in the subject, electrical engineers are already being called upon to design transformers, rectifiers, and other equipment rated at several million volts, for accelerating bombarding particles to velocities sufficient to penetrate into atomic nuclei, against their repulsion. Some of the newly produced modifications of chemical elements (isotopes) are not only radioactive, but the particles and radiations which they emit are more powerful than those of radium. This opens a new field of applications in medical sciences, in studies of materials and structures, and wherever such radiations and emanations have been found useful. The speaker had before him several charts showing the nuclei of some lighter elements and the primordial particles out of which atoms are supposed to be built up. The two fundamental particles, the positively charged proton and the non-charged neutron are of practically the same weight as the hydrogen atom. Hence, if atoms are built out of these particles their atomic weights should be multiples of the atomic weight of hydrogen. This is actually the case for each pure "isotope" or kind of element, but not for chemically pure elements in the usual sense, most of which consist of a mixture of two or more isotopes. The speaker showed a part of the periodic system of elements, with the known isotopes of each indicated separately. He also pointed out the method by which the isotopes of the lighter elements are supposed to be composed of protons, neutrons, and so-called alpha-particles. With regard to the transmutations of lighter elements, he chose the production of radioactive nitrogen from one of the isotopes of boron. Such nitrogen is unstable and is gradually converted into carbon with the emission of positive electrons. This reaction is of interest because Madam Curie's daughter, Irene, and her husband Joliot, were awarded a Nobel prize for it, and also because high-speed neutrons

are liberated in it which can be used for other bombardments. For his other example, Professor Karapetoff chose the production of radioactive sodium, by bombarding the usual modification of sodium with nuclei of heavy hydrogen. Negative electrons of high velocity and extremely penetrating electromagnetic radiations are emitted and the unstable sodium is gradually converted into stable magnesium. This phenomenon should be of considerable practical importance, replacing scarce and expensive radium.

R. H. O.

Fractional Distillation of Coal.—(*The Gas World*, Vol. CVIII, No. 2804.) A new method of fractional distillation of coal which permits the greater part of the oil contained in it to be recuperated is being tried in the Prosper Works of the Rheinishen Stahlwerke. It is based upon observations of the manner in which the distillation of the coal takes place during gas production. It is noticeable that as the coal in the retort is heated by the hot side walls the distillation takes place fractionally, the lighter parts being driven off first and the heavier ones after. The temperature of the coal near the walls is much greater than that in the center of the mass, so that as the heavier parts of the distillate filter through the mass they tend to deposit in the center of the mass. As the heat moves towards the center the point at which this deposit takes place also moves so that during the heating process two walls of heavier distillate deposits are formed in the charge; these walls progressively approaching each other until they finally meet in the center at the end of distillation. It is in the lighter parts of the distillate that most of the oil is to be found. In order to obtain separation of the two types of distillate arrangements are made which include tubes inserted through the center line of the retort doors, running through the door into the interior of the chamber. In this way, during the first part of the distillation they communicate with the center mass of coal, lying between the two approaching walls of heavy distillate. As the heating of the coal progresses, the natural tendency of the heavy distillate to condense is used to permit a separation between the distillate given off by the white hot mass and that obtained from the cooler center. A suction pump draws off gas through the center of the mass, and the distillate is filtered through the cooler portions of the charge and the heavier distillate deposited.

R. H. O.

Fiber Glass—A New Insulation for Electric Apparatus.—K. N. MATHES. (*General Electric Review*, Vol. 41, No. 5.) The origin of fiber glass is lost in antiquity. About 1859, it was proposed that

glass fibers might render glass more useful in new directions but until recently little active investigation resulted. During the last few years glass companies in the United States have undertaken the commercial production of glass fiber by new and ingenious methods. Glass marbles are fed into small electrically heated furnaces. The molten glass flows by gravity through a row of fine holes in a precious metal die or bushing and comes out as fibers. To make these fibers extremely fine, the hot plastic strands are stretched to produce continuous filament fiber by being wound upon a rapidly rotating drum or they are pulled out in a rapidly descending column of steam which breaks up the fiber into four to eight inch lengths (called staple fiber) and deposits them as a narrow felt or sliver upon a continuous moving belt. The sliver may be reduced in size before spinning. It presents a rougher finish than the continuous filament glass which is usually spun directly into thread. The glass threads may then be woven or braided by ordinary cotton machinery slightly modified. Fiber glass cannot be considered as a substitute for any specific insulation and at present cost is not competitive with cotton for many uses. However, its stability at high temperatures and in corrosive atmospheres suggests advantageous use under such conditions. The indications are that it will progressively assume greater importance in the insulation of large apparatus where such properties are important. It may also find application in the insulation of apparatus exposed to certain extreme types of service conditions. At present fiber glass is being actively studied in the laboratory and is undergoing service trials for various types of applications. The results of such tests will offer the most valuable information as to its advantageous uses.

R. H. O.

One Eye Better Than Two.—This is what is claimed in the field of chemical volumetric analysis by the Fisher Scientific Company. They have developed an all purpose electrometric titration apparatus that is a sensitive instrument which employs the latest electronic circuits in acting as a universal chemical indicator making possible many analyses not otherwise practicable because of turbidity, precipitates or reaction idiosyncrasies. The Fisher titrimeter will perform acid base, oxidation-reduction, pH and conductivity titrations, and measure D.C. voltage and resistance. These titrations are made through the detection, amplification and observation of electrical changes between electrodes in a solution before, at and after the end point. Since every chemical reaction involves electrical changes, the direct electrical method of detecting

these changes is preferable to the use of chemical indicators which do not respond as quickly and are not as sensitive to the small potential changes occurring at the end point. The electrometric method indicates these electrical changes instantly and directly as contrasted with chemical indicators which reflect the changes indirectly. While the electrical method of detecting end points is not new, it has not been used extensively in the past because a thoroughly satisfactory instrument for this purpose had not heretofore been developed. This new Fisher Titrimeter employs a unique circuit which utilizes the modern amplifying tube and the sensitive "magic eye" of radio to produce a sturdy and compact instrument which indicates conspicuously minute changes of potential between electrodes in a solution.

R. H. O.

Water Borne Outbreaks in U. S. and Canada, 1930–36, and Their Significance.—The report of the Committee on Water Supply of the American Public Health Association has been conveniently reprinted by Wallace and Tiernan, Inc., in pamphlet form. From the mass of factual data given it is concluded that while there has been a continued decline in typhoid fever rates during 1930–36 there has not been a similar decline in the number of water borne outbreaks reported. During these years there were reported water borne outbreaks of Flexner dysentery, amebic dysentery and jaundice in addition to typhoid fever and miscellaneous diarrheas. In both countries there appears to be need for far more strict supervision over public water supplies of the small cities of the 1000 to 5000 population group. The water supplies of rural schools, public institutions and summer resorts are especially in need of more strict supervision. During the period mentioned 44.7 per cent. of the water borne outbreaks reported in U. S. were in the summer season; in Canada 63.1 per cent. were in the late winter and spring months. Cold weather and thaws appear to have a definite relationship to water borne outbreaks in Canada. Untreated ground water supplies—especially shallow wells contaminated by surface pollution—was the principal cause in U. S. while in Canada the use of polluted untreated surface waters was the principal cause.

R. H. O.

Stanton Reinforced Concrete Air-Raid Shelter.—(*The Gas World*, Vol. CVIII, No. 2806.) Air raid shelters are now being manufactured by the Stanton Ironworks Company, Limited, Nottingham, England. They are constructed of spun concrete pipes 7 ft. 6 in. in diameter and 4½ in. in thickness, specially rein-

forced to withstand shocks. The standard size shelter provides accommodation for 50 persons, but larger or smaller sizes are available. It may be buried at any required depth and covered with concrete, earth, sand or a combination of these materials in successive layers. Alternative types of entrance are available—a vertical shaft and ladder or a flight of steps leading to a small air lock chamber. All doors are gas tight and while people are entering the air lock chamber from outside the shelter the door of the main chamber remains closed. A wash basin and first aid box are provided in the air lock compartment. Provision has been made for a constant supply of filtered fresh air and for this purpose a hand driven air pump is provided. Pressure in the inner chamber is maintained at slightly higher level than that of the outside atmosphere as a further precaution against the entry of gas. An exhaust valve prevents air pressure within from becoming too high and provides a means of exit for stale air. Drainage to a sump at one end of the shelter is provided. There is equipment for drinking water, storage of food, lighting, gas masks, and fire extinguishers. The Stanton Ironworks Company are themselves installing eight of these shelters to provide protection during air raids for key men who must remain at their posts. Telephonic communication may be installed as well as a wireless set.

R. H. O.

Corrosion by the Impact of Falling Drops.—G. WELTER. (*Engineering*, Vol. CXLV, No. 3774.) In view of the practicality of this question a series of tests has been made in conjunction with Dipl.-Ing. Gockowski, in the Metallurgical Department of the Institute for Chemical Research in Warsaw, with the hope to obtain results which would show whether or not the velocity of impact of the corrosive medium had a decisive influence. Practical examples of cases in which corrosive media and materials come into contact at high relative velocities are furnished by the impact of sea water on the floats of seaplanes and the hulls of steamers, and of atmospheric precipitation on the metal screws of aeroplanes. The tests were carried out on a qualitative basis, a 3 per cent. sodium chloride solution being chosen as the corrosive medium. The solution was brought into contact with the materials in the form of drops falling from a height varying from 1.5 m. to 5 m. Tests were made on four types of aluminum alloy, a magnesium alloy of Elektron type, and a soft carbon steel. It was arranged that about 20 drops of the solution issued from its container in one minute. With an Al-Mg-Cu alloy after 13 days drop impact of the solution there was considerably more attack than in the case of mere moistening of the

specimen for the same period. In this case the specimen was cut so that the surface was transverse to the direction of rolling of the material. Similar comparative effects were obtained by an aluminum-copper-nickel-magnesium alloy of the R. R. type. Deep local corrosion was found after an eight-day test. Different results were obtained with soft carbon steel and the Elektron type alloy. With both of these materials the attack was confined mainly to surface effects, without any considerable penetration into the body of the material. The drop test gave the more severe corrosion of the surface than the moistening test, particularly in the case of the Elektron alloy.

R. H. O.

Experiments May Help Solve Riddle of Growth Substances.—When cuttings of many plants are treated with a suitable solution of one of the recently discovered growth substances or plant hormones, they grow more roots and grow them more quickly than untreated cuttings. Plant scientists accept this as a fact, but they are still puzzled as to how it happens. W. C. Cooper of the U. S. Department of Agriculture has opened new lines for investigation by reporting a series of experiments which throw new light on the problem and indicate that the real root-forming substances are already in the plant and not in the treatment. Several chemicals are known to promote rooting. Cooper used indole-3-acetic acid, one of the first chemicals identified as a growth substance. He treated lemon cuttings—soaking the base of each cutting in a solution of the chemical—planted part of them, and got the anticipated response—more and stronger roots than from untreated cuttings. Part of his cuttings he did not plant. Instead he cut off the treated base sections and again treated the shortened cuttings. The second treatment did not stimulate nearly so much root formation as the first treatment. Doctor Cooper says that the probable explanation of these conflicting results is that the chemical treatment causes the downward transport of naturally occurring root-forming substances which are already in the plant and which are necessary for root formation. For convenience in the discussion of these substances, they have been named rhizocaline. A 20-hour treatment of lemon cuttings apparently drew down about two-thirds of these substances and concentrated them in the base. In a 40-hour treatment the rhizocaline movement was practically complete. If the treated base was cut off after 20 hours this removed about two-thirds of the rhizocaline and a second treatment resulted in some root formation. But after a 40-hour treatment had concentrated practically all the rhizocaline in the base, shortening the cutting removed

practically all the rhizocaline and the second treatment did not promote rooting, even though the cutting absorbed the indole-3-acetic acid. Cooper's experiments with various other plants indicate that plants which do not root readily when treated—delicious apple cuttings, for example—are lacking in rhizocaline. The chemical nature of rhizocaline has not been discovered.

R. H. O.

California Fair to Use New Light Sources.—(*Power Plant Engineering*, Vol. XLII, No. 6.) New light sources in the form of tubular fluorescent lamps will find their first large-scale outdoor application at California's 1939 International Exposition, according to W. P. Day, Vice-President. The new lamps, announced by General Electric engineers, utilize invisible sunrays imprisoned within their walls to bombard chemical powders to produce cool light sources that duplicate all the pastel tints of the rainbow. Fluorescent powders compounded and especially heat-treated in the General Electric laboratories hold the secrets of high efficiency and color producing qualities of the new light sources. Within the lamp bulbs is a trace of mercury, a small amount of argon gas at low pressure, and a coating of fluorescent powders, selected and blended to produce the colored light desired. When current is applied, the argon serves as a "starter" and in a fraction of a second a feeble blue light with a large component of invisible ultra-violet radiation is generated inside the tube. This radiation strikes the fluorescent coating and is re-radiated in the visible range of the spectrum. Each powder has its own characteristic wave band with which it responds to the ultra-violet, thus forming its own particular color of emitted light. San Francisco's Fair will become a milestone in lighting progress by pointing the way to the future widespread use of this new lamp in hundreds of applications where both utility and decoration are of permanent importance.

R. H. O.

Sulfamic Acid, a New Industrial Chemical.—M. E. CUPERY. (*Industrial and Engineering Chemistry*, Vol. 30, No. 6.) Sulfamic acid, HSO_3NH_2, is a strong inorganic acid in crystalline form. In a new production process, urea is first dissolved in excess cold sulfuric acid. Oleum of suitable sulfur trioxide strength is then added, and the reaction is allowed to proceed under controlled conditions. During the reaction carbon dioxide is evolved, and the sulfamic acid formed precipitates from the solution. The product is isolated by filtration and purified by recrystallization from water. Since the reagents used in the process are available in unlimited

quantities, it is now possible to produce the acid as a new industrial raw material. Sulfamic acid is a colorless, odorless, nonhygroscopic, crystalline product which may be handled and packaged commercially in a solid form. In aqueous solution it is highly ionized, forming strongly acidic solutions. Under ordinary conditions sulfamic acid is practically stable in water; at increased temperatures it is slowly hydrolyzed to ammonium acid sulfate. Similarly, alcoholysis yields ammonium alkyl sulfates. The salts of sulfamic acid are stable in neutral or alkaline solution, and such solutions may be evaporated with heating without hydrolysis of the amide group. One of the most promising potential industrial applications for sulfamic acid is the use of certain of its salts as flame-proofing agents for fabrics, paper, and other combustible material. By virtue of its unusual properties, the acid represents an important addition to the group of commercial acids represented by lactic, acetic, formic, tartaric, oxalic, and similar acids, and should be especially useful for applications in which a highly ionized nonvolatile acid is desired or where precipitation of insoluble salts must be avoided.

R. H. O.

Salmon Pass Galloway Plant.—JAMES WILLIAMSON. (*Engineering News Record*, Vol. 120, No. 22.) Fears that there may be a large loss of young salmon in the turbines of the Bonneville power plant on the Columbia River do not find support in experience gained at hydroelectric plants in Scotland. The problem of passing smolts (salmon at the stage when they first decend to the sea) through water wheels was studied at the power stations in the Galloway Water Power Scheme on the River Dee in the southwest of Scotland. Provision for the ascent of salmon has been successfully met by fish ladders of the pool and orifice type with large resting pools at intervals. For descent, most of the smolts are attracted to the plant intakes. At one of the plants, which is typical, there is a variation of head between 90 and 115 feet, and there are vertical turbines with runners about 9 feet diameter space between blades about 10 in. max. and speed of 214 r.p.m. Tests were made which showed no harm to the fish due to the rapid change of a few seconds from high pressure at the entrance to the turbine to partial vacuum at the outlet. In these, a special tank with observation windows was devised in which small fish were gradually subjected to increasing pressure up to 100 feet maximum head and a sudden release in two seconds to 15 feet of vacuum head. After the station started up very few dead or damaged fish could be found in the tail race.

R. H. O.

Producer Gas Driven Vessels.—D. BROWNLIE. (*Engineering*, Vol. CXLV, No. 3776.) Great interest attaches to one of the results which have followed the efforts being made in Germany to reduce dependence upon imported liquid fuel; this is the introduction of the producer gas driven ship, using producer gas generators operated with coke, anthracite, or wood. In the Humbolt-Deutz power plant, the generator is situated forward of the center of the ship with two vertical eight-cylinder, single-acting four-stroke gas engines farther aft, the engines being side by side and each driving one screw. The two engines are each of 375 brake horse-power and they run at 375 r.p.m. The engines are of the non-reversing type, and the special Zahnräderfabrik-Augsburg reversing gear, which includes disc clutches operating in oil, allows of the engines driving the screws ahead or astern, or idling, merely by the operation of a lever on the captain's bridge, which is also provided with two other levers, to vary the speed of revolution of each engine as well as a steering wheel. It is claimed that the general manœuvering of producer gas ships of this type is easier than with a steam ship. The normal duty of the ship, known as the Harpen I, as with the steam and Diesel tug-boats of the Harpen Company, is to tow three barges each carrying about 1166 tons of coal at a maximum speed of about 2.7 knots against the stream, the actual journey from Duisburg to Mannheim on the Rhine, a distance of 54 miles, being accomplished within eighteen hours. From calculations that have been made, producer gas driven ships are much the most economical, costing only about 0.10 d. per brake horse-power with small coke and anthracite as against 0.15 d. for normal superheated steam using ordinary coal, 0.13 d. for high steam pressures and superheated steam pressures, and 0.16 d. for the Diesel engine using cheap fuel oil, the use of high grade oil costing 0.37 d., nearly four times that of producer gas. According to the latest information, the producer gas consumption has now been reduced to 0.75 lb. to 0.77 lb. of metallurgical coke per brake horse-power, only about half that of steam generation on actual fuel cost per horse-power.

R. H. O.

Dome for World's Largest Telescope Presents Unusual Insulation Problem.—(*Heating, Piping and Air Conditioning*, Vol. 10, No. 6.) Mt. Palomar, California, about 60 miles from San Diego, the world's largest astrophysical observatory, is nearing completion. It will be ready to operate in 1940. One of the many problems to be solved for this tremendous project, in which many branches of science, engineering, and industry have cooperated, was the method of insulating the dome. The dome, 135 ft. in diameter, will be

rotated so that the opening 30 ft. wide and over 100 ft. in length is held in line with the telescope wherever it may be pointed. Huge sliding shutters will close the opening at dawn when the atmosphere is at its coldest, and it is necessary to maintain this low temperature inside the dome in order that when the shutters are opened in the evening the inrush of cool air will not change the temperature to an extent as to interfere with the operation of the telescope. The dome insulation chosen was aluminum foil. In addition to high thermal efficiency, the insulation must be unaffected by possible vibration, fireproof, held firmly in place, must not warp or sag, and must be enduring. The foil is made up in metal panels 5 inches thick holding twelve layers of crumpled foil. Layers are separated by contact between high points and completely fill the depth of the panel. The insulating panels are supported and held in line by structural T's of aluminum standing in vertical planes and rolled to conform to the curvature of the dome. This concave aluminum surface forms the interior surface of the dome and this attactive metal finish is set off by the slender lines of the T's which rise from the observation gallery and arch high overhead, converging toward the top of the dome. The construction has high utility value because of high reflectivity and low emissivity of radiant heat. This means that the transfer of radiant heat between the telescope and the revolving dome will be reduced to a minimum which will add materially to the insulation of the telescope.

R. H. O.

Black Light Detects Oil Leakage.—(*Electric Journal*, Vol. 35, No. 6.) Oil may be good for troubled waters, but it is very definitely not desirable on the waters of rivers and harbors around oil refineries or where oil tankers are docked. Oil men take pains to prevent leakage from their tanks and vessels, but one of the really difficult problems is to detect such leakage at night. Ordinary incandescent lamps are not very effectual for discerning oil on water after dark. However, under the influence of ultraviolet light, oil strongly fluoresces, appearing somewhat like milk, and is thereby made very conspicuous. A large Eastern refinery has used with considerable success a portable unit consisting of a transformer which provides the proper voltage to an 85-watt lamp, and a black glass envelope as a visible light filter mounted in a reflector.

R. H. O.

Air Conditioning a Liner.—(*Automatic Heat and Air Conditioning*, Vol. 9, No. 6.) Air conditioning, the so-called "infant industry," has taken on innumerable roles in its brief span of years.

While many of the large passenger vessels have enjoyed air conditioning in their dining rooms and cocktail lounges, conditioned air has at last really gone to sea, with air conditioned bedrooms embodying the latest step in sea-going luxury. The first vessel on the Pacific to be so equipped—and according to the owners, the only such vessel in the world—is the Matson Navigation Company's S.S. Matsonia. She is a 17,000 ton, 22 knot, de luxe passenger express liner, in service between San Francisco and Honolulu. Last winter when but barely ten years old she was modernized. Perhaps the most radical change from the traveler's standpoint was the rearrangement of part of "B" deck to provide for the accommodation of lanai or verandah cabins. These are the quarters that are equipped with year-round air conditioning. The system was not designed primarily as a cooling job with respect to the outside temperature. It was essentially designed as a dehumidifying system. The cooling load was figured on a seven degree differential between outside and inside, but sufficient capacity was installed to maintain an average humidity of 45 per cent. at all times. The total amount of air supplied is approximately 3000 c.f.m. proportionally distributed to each individual room. An air conditioning unit was installed in one of the storage rooms in the midship section. The unit is a self contained assembly of fans, cooling coils (designed for brine operation), heating coils and air filters. Outside air conditions were set up at 85 deg. F. dry bulb, with a 75 deg. wet bulb; inside conditions were to be maintained at 78 deg. F. and 45 per cent. relative humidity. Cold brine from the ship's stores refrigerating system is injected into a pump suction at 5 deg. F. and the quantity is regulated thermostatically.

R. H. O.

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Old Instruments and Devices.—Often in the progress of scientific endeavor there comes to investigators and workers a desire for knowledge of how certain problems were solved by those of years ago who did not have the facilities of today. In fact when time is taken to inquire into facilities of only one hundred years ago, it is surprising to learn of the ingenious devices that existed. The editor of *Sands, Clays and Minerals* in its Vol. III, No. 3, in a note preceding an article on Old English Instruments, refers to the importance of the study and collection of early apparatus of scientific interest. He states that the historical aspect of science is partly manifested in an increasing number of serious contributions to books and journals devoted to the subject. Early instruments form a particularly valuable and fascinating study. The article above mentioned is a reproduction of an early catalogue which is

illustrative of the type of instruments then in use and the price at which they were sold. The catalogue is reproduced through the kindness of Mr. Thos. H. Court, well known authority on early scientific instruments, who has placed its date as 1764–5. It contains a price list of early "Philosophical, Optical and Mathematical Instruments Made and Sold by Benjamin Martin, At his Shop, the Sign of Hadley's Quadrant and Visual-Glasses, near Crane-Court, in Fleet-Street."

In connection with the same general subject a following article in the same number of the periodical on Early Technical Balances by A. Barclay is of interest. This is the fundamental apparatus without which no scientific progress could be made possible. It is the purpose of this article to trace briefly the history of the balance as used by the technical worker during the period commencing with the middle of the sixteenth century down to the introduction of the precision balance in the latter half of the eighteenth century. Several interesting accounts and illustrations exist of the balances employed by the metallurgist, chemist or physicist during this time. The notes which follow are chiefly confined to these workers, occasional deviations being made for the illustration of certain stages of development, or for purposes of comparison. The starting point of the period is the well known De Re Metallica of Georgius Agricola, the first Latin edition of which was published in 1556. In this is described three balances of different sensitivity for assaying ores. Other works are cited and the article is descriptive of the various makes. The illustrations accompanying the article are of special interest. It is seen that the need for reliable balances in technical work was realized as an essential as long ago as mediæval times by those who treated the matter seriously, and there is no doubt that Agricola was fully aware of the importance of consistent weighings, though how far he succeeded is open to speculation. However his balances were as delicate instruments as some of those of the first century Romans, whose method of suspending a beam from a ring fixed to its top center gave results which were, to say the least, an approximation to the truth.

R. H. O.

Forest Service Develops Two-Way Radio for Fire Fighting Vehicles.—Development of a new two-way radio communication unit adapted to fire trucks and cars used in fighting forest fires was announced recently by F. A. Silox, Chief of the Forest Service of the U. S. Department of Agriculture. Vehicles used in fire fighting or patrol on National Forest areas will be equipped with the new radiophone device in the near future so that forest rangers and

other officers can keep in touch with their headquarters at all times. Work on the new device has been carried on by A. G. Simson, radio engineer of the Forest Service, and associates. They have perfected a way to use the regular short wave instead of the ultra-high frequencies used by police cars and others on patrol duty for two-way communication. The new unit permits a greater communication range than the ultra-high frequencies. "The transmitting range under adverse conditions is at least 25 miles and tests under average conditions show the outfits to have a range up to 250 and even 500 miles," Mr. Simson stated. "These distances are phenomenal when it is considered that the antenna used is only a 7 foot metal fish pole of the ordinary hardware store variety." The Forest Service recently tested the new radiophone device by talking from Portland, Oregon, to Reno, Nevada, and distances beyond, with excellent results. The outstanding feature of the apparatus is a small iron box containing the matching unit which permits unusual efficiency in transferring energy from the transmitter to the antenna and conversely, from the antenna to the receiver. The power is furnished from the regular 6 volt car or truck battery.

R. H. O.

A New X-ray Stereometer.—C. D. MORIARTY (*General Electric Review*, Vol. 41, No. 6). When movie dramas are produced in three dimensions the audience will be able to give expression to pent-up emotions by strangling the villain or protecting the heroine; for the actors will be projected off the screen to within each reach of everyone. The same principle that will thus bring within reach an actor on the screen in the future now allows us to touch a defect in the middle of a piece of solid steel and measure its depth relative to the surface. The device by which this is accomplished is the stereometer. To properly visualize or see three dimensions there must be coördination between the two eyes, the brain and experience. These three elements operate as a unit. In x-ray stereoscopic work there seldom occurs a condition that is identical with normal experience. The x-ray views may be taken at a greater or smaller angle than the fixed distance between the eyes would permit in normal vision, resulting in either greater or less third dimension. Consequently any instrument used in conjunction with a stereoscope to measure accurately the third dimension must ignore normal experience. The principle of the stereometer is explained by a simple experiment. Hold a pencil horizontally in one hand at arm's length and pointing across the line of vision; in the other hand hold another pencil vertically about half way

between the horizontal pencil and the eyes. Look at this combination first with one eye and then with the other. The vertical pencil will appear to shift with the closing of alternate eyes, about half the length of the horizontal pencil. Bringing the pencils closer together decreases the shift until the pencils touch. There is a mathematical relation between this shift and the distance between pencils or the third dimension. The stereometer is an ingenious device which needs only inexperienced adjustment and allows the radiologist to determine very quickly the overall thickness of an object, the thickness of an internal part of an object, the relation of defects to one another or to either surface, or the amount of dip or rise to a "pipe" defect.

R. H. O.